A GRAPHICAL DESIGN PROCEDURE FOR RADIANT PANEL HEATING

A GRAPHICAL DESIGN PROCEDURE FOR RADIANT PANEL HEATING

Prepared for

REVERE COPPER AND BRASS INCORPORATED

by

F. W. Hutchinson

A SIMPLIFIED, RAPID, GRAPHICAL

DESIGN PROCEDURE

Retaining the Accuracy of the Complex Rational Method

ANSWERS THE QUESTIONS:

1 *What must be the panel area?*

2 *What size and spacing of copper tube is required?*

3 *What must be the water temperature?*

4 *What size heating plant is needed?*

FIRST EDITION 1945

F O R E W O R D

The heating contractor and the consulting engineer have been in urgent need of a straightforward, step-by-step radiant panel heating design procedure which would combine speed and simplicity with inherent engineering accuracy. During the last five years substantial progress has been made in placing radiant heating design on a rational and scientific basis, but this work has been of little practical value because of its mathematical complexity and numerical tediousness; no heating contractor can be expected to set up and solve seven simultaneous equations each time he is asked to submit a competitive bid.

As alternatives to the impractical and time-consuming analytical procedures, many rule-of-thumb methods have been introduced. These are, at best, of limited value and their use always leaves open a possibility that — for a particular case — the assumptions and short cuts and simplifications may lead to serious error. Further, in localities where competition is keen, the contractor can no more afford the economic luxury of conservative over-design than he can the operating risk of under-design.

The obvious solution of the above problem is to retain the exact rational method, but make it available in a form such that its mathematical complexity and numerical tediousness will vanish. If this can be accomplished the entire problem of exact design is reduced to a rapid and routine procedure. As a service to all who are working in the field of panel heating, Revere Copper and Brass Incorporated has sponsored an impartial engineering study leading to the development of a simple graphical method for rapidly designing a panel heating system.

This work has been carried on under the direction of F. W. Hutchinson and is based on the rational heat balance procedure developed in the series of technical papers, of which he is co-author, which have been published in the Transactions of various engineering societies[1,2,3,4]. The only instruction which Revere Copper and Brass Incorporated gave to the Consultant was that the method must be simple, yet must give results comparable in accuracy with those obtainable from the complex analytical procedure.*

** Refers to Bibliography, page 55.*

Probably the most serious obstacle to the more rapid development of panel heating has been the engineering expense required for careful design. The five-step procedure given in this bulletin — involving only one arithmetical calculation — not only eliminates the excess design time, but actually makes it possible to design a radiant system with less effort and in less time than would be required for a radiator, convector, or warm-air installation. To achieve this simplicity has been no easy task. Literally thousands of man-hours of skilled effort have been built into the graphs which constitute the basis of this design procedure. If each one thousand hours of such effort succeeds in reducing by a small fraction the skill, time, and expense required for accurate panel design, the objective of Revere Copper and Brass Incorporated will have been fully realized.

Vice President

REVERE COPPER AND BRASS INCORPORATED

TABLE OF CONTENTS

Chapter I: INTRODUCTION

The purpose of design in a radiant panel heating system is to determine the minimum size of a given type of heating panel needed to establish comfort in a particular structure under the most extreme outside conditions. Secondary purposes are to fix the temperature of water required for the system, to select a tube arrangement for the panel, and to evaluate the total heat loss from the structure; this latter figure is needed in order to determine the size of heating plant. Before discussing the details of design it will be well to list the various factors important to a panel system, segregating them into two groups: A. Those which can be assigned numerical values before the design is started; B. Those which are evaluated as a result of the design procedure.

A. Known Factors

a. The design value of the outside air temperature, t_o, is selected from Weather Bureau or Handbook data just as it would be for any type of heating system. This temperature is indicative of the most extreme conditions for which the heating system would be expected to maintain comfort.

b. The design value of the panel surface temperature, t_p, is the temperature at which the panel would be expected to operate under full load. Limitation of this temperature results primarily from structural considerations such as the hazard of causing cracks in a plaster panel if the temperature exceeds a critical value. Based on experience with the type of panel which he intends to use, the designer must fix the maximum permissible surface temperature. Plaster or concrete panels used in wall or ceiling are commonly designed for a maximum surface temperature of either 100°F or 120°F; floor panels — regardless of the type of construction — should be limited to 85°F for sections on which people will walk and 100°F for border panels that will not be stepped on.

c. The ventilation rate, V, in air changes per hour is one of the most important factors in determining the performance of a panel system. If the structure is mechanically ventilated the term V can be readily evaluated by multiplying the cubic feet per minute of untempered* outside air by 60 and dividing by the room volume. When ventilation air enters by infiltration only — as in most residences — the value of leakage through window cracks, etc. is calculated in the usual way (*ASHVE Guide*) and then converted to air changes per hour by dividing the cubic feet per hour by the room volume.

d. The equivalent overall coefficient of heat transfer, U_e, can be readily calculated from the areas of the various parts of the structure (as taken from the architectural plans) and from the overall coefficients of the different parts as determined in the usual way (*ASHVE Guide*). These known values are then substituted in the equation** which defines U_e,

$$U_e = \frac{U_g A_g + U_w A_w + U_i A_i + U_c A_c + U_f A_f}{A_t} \qquad (1)$$

where subscripts g, w, i, c, and f refer to unheated areas of glass, exterior wall, inside partition, ceiling, and floor. The denominator, A_t, is the total unheated surface area of the enclosure and is, of course, equal to the sum of the areas which appear in the numerator. The total enclosure area can be taken from the plans of the building, but since the required area of heating surface is unknown, the term A_t is likewise unknown. In practice, however, the influence of heated area on A_t is usually so small that an accurate design can be attained by estimating A_t as 80% of the total room surface area. On this basis U_e is evaluated and the design procedure followed to find the required panel area, A_p; this first value of A_p could be used to evaluate a more exact A_t which would then lead to a second and more precise determination of A_p. In theory this procedure of successive approximations might appear slow, but actu-

---

* If outside air is tempered before admission an approximate ventilation rate — based on equivalent untempered outside air — can be calculated from the equation, $V = \left[\frac{68 - t_x}{68 - t_o}\right] V_a$ where V_a is the actual ventilation rate and t_x is the temperature of the tempered air.

** This equation is set up for a room from which all transmission losses are based on the same value of outside air temperature. If the design outside air temperature for any part of the enclosure (as the floor) differs from t_o, the term for that surface in the numerator of equation 1 should be corrected by a factor $\frac{68 - t_y}{68 - t_o}$ in which t_y is the design exterior air temperature for the area in question.

ally the influence on U_e of a change in A_t is usually so small as to make it unnecessary to go through the design procedure a second time. It should be emphasized, however, that by repeated approximations any required degree of accuracy can be obtained.

e. The temperature drop, Δt, of the hot water passing through the panel will now be investigated. Effective design requires a high degree of uniformity of panel surface temperatures; this can most readily be attained by restricting the temperature drop of the water to 10°F or less. In a structure having many rooms, or many panels in one room, it will usually be necessary to permit some variation in Δt since with a single source of hot water there would be no other way of meeting the design value of the mean water temperature, t_w.

B. *Unknown Factors*

All to be determined from the design procedure.

The unknown factors are:

f. The panel area, A_p.

g. The panel rating, Q_p, Btu/(hr)(sq ft), and the required energy input to the room, Q_pA_p.

h. The air temperature in the room, t_a, when operating at maximum load and under conditions of optimum comfort.

i. The flow rate and temperature drop of water passing through the panel and the entering hot water temperature are all dependent variables some of which can be selected for a given installation and the others then calculated. The procedure for doing this will be illustrated in a subsequent numerical example.

j. The size and spacing of the copper tubes which make up the heating source within the panel.

k. The mean radiant temperature and the average temperature of unheated room surfaces are factors of interest but not of direct importance to the designer. They can, however, be readily evaluated by using the data available after the design procedure has been completed.

Chapter II: DESIGN PROCEDURE

1. *Determination of the ventilation correction factor, V_c, and of the geometry correction factor, K.*

A series of geometry charts — each one for a given ceiling height — are given on pages 17 to 21. Turn to the chart for a ceiling height equal to that of the room in question. Enter the chart at room width, rise to the curve for room length (see *blue* example line on each chart) and move horizontally left or right to intersection with the curve for the known ventilation rate, V; from this point rise to the upper scale to read the ventilation correction factor, V_c, and move horizontally to the scale at left of chart to read the geometry correction factor, K.

2. *Determination of panel area and rating and of room air temperature.*

Turn to the table of contents (page 5) and select the proper design chart for the panel type (as wall, floor, or ceiling) and for known maximum panel temperature, t_p, and for design minimum outside air temperature, t_o. Then refer to this chart and enter the equivalent overall coefficient scale at the known value of U_e and the ventilation factor scale at the known value of V_c. From these two known scale points draw lines (as shown by the *blue* example lines on each chart) which intersect at the design point.

By moving horizontally right from the design point, the optimum comfort air temperature in the room (for design outside conditions) is read from the scale at the edge of the chart, while a line from the design point parallel to the red rating lines will give the panel rating, Q_p, in Btu/(hr)(sq ft). Lastly, draw a vertical line from the rating point to intersect the proper geometry correction factor line and from this intersection move left to read the percent of the wall, floor, or ceiling which must be heated; from this percentage A_p can then be readily determined.

3. *Determination of size and spacing of copper tube within the panel.*

No generally accepted method of calculating the heat transfer from an embedded coil has, as yet, been developed. Noting the lack of an adequate rational procedure, Revere Copper and Brass Incorporated sponsored an experimental project to investigate the thermal characteristics of a series of eight panels; the unit panels were constructed with different sizes of copper tubing and with tubing coiled on different center-to-center spacing. From the laboratory test data thermal coefficients were evaluated permitting extrapolation of the actual test results to a wider range of panel ratings; in this way the data given in Tables I, II, and III (pages 53 and 54) have been compiled. These three tables are for plaster panels in which the copper tube is located ¼″ in from the face of the panel and below, but in contact with, expanded metal lath. In all cases the test panels were insulated at the rear and around the sides (test sections were 4′ × 4′) in such a manner as to reduce to a negligible quantity the heat transfer from any surface except the panel face. For a copper coil embedded in concrete (the coil surface ¼″ back of the panel face) the value of $(t_w - t_p)$, for a given rating, was found to be approximately 25% smaller than the corresponding value for plaster.

Each of the three tables — for a fixed design value of the panel surface temperature — gives the required mean water temperature as a function of the panel rating, Q_p, and of the size and spacing of the copper coils embedded in plaster. Once the rating has been determined (as in design step 2, above) reference to one of the tables will permit selection of a tube size and spacing. In general, small closely-spaced tubes will be more effective thermally than large widely-spaced ones; the closer the tubes are spaced — for a given panel rating — the more uniform will be the surface temperature.

A low mean water temperature is desirable because it is indicative of good surface uniformity and also because it serves to reduce the temperature drop from coil to surface, thereby minimizing the thermal stresses that occur because of temperature variation through the body of the plaster. Whenever other conditions will permit, a tube arrangement should be selected which will allow operation with a mean water temperature not greater than 160°F.

4. *Determination of flow rate.*

The flow rate chart (page 52) presents a graphical method of determining the

gallons per minute flow required through a given panel, or — for a predetermined gpm — the required temperature drop of the water as it passes through the panel. The area scale at the bottom of this chart is constructed for a range of 0 to 10 square feet, but this can obviously be raised to 0 to 100, 0 to 1000, etc. by setting off the necessary number of decimal places; thus the chart can be used for any area of panel whatsoever. Entering at the known area, rise to intersect the line for the known panel rating, then move horizontally to intersection with line for known temperature drop and from this point rise to read the gpm from scale at upper edge of the chart. If the flow rate is known and the temperature drop is to be evaluated the procedure is essentially the same except that the solution is obtained at intersection of the known gpm line with the horizontal drawn, as before, through the panel rating intersection.

In a multi-panel installation the entering water temperature must necessarily be approximately the same for all panels. For such a system the temperature drop cannot be arbitrarily selected since it must satisfy the equation,

$$\Delta t = 2(t_e - t_w) \tag{2}$$

in which both t_e and t_w (entering, and mean water temperatures, respectively) are fixed by design conditions. In this case Δt will have to vary from panel to panel and flow rates needed to obtain such variation will then be obtained from the flow rate chart.

An alternative multi-panel design procedure would be to fix arbitrarily the flow rate (possibly at some constant value for use in all panels of the system) and then obtain Δt from the flow rate chart and t_w from equation 2; then going to Table I, II, or III with t_w and Q_p known, the required tube arrangement could be selected. This method is subject to definite limitation, however, since in many cases there will not be a commonly used tube arrangement that will meet the specific requirements of both Q_p and t_w.

5. Determination of mean radiant temperature and of boiler load.

When a panel design is carried out by the procedure which has been indicated there is no need for evaluation of the mean radiant temperature, *mrt*. If, however, the designer wishes to determine the *mrt* he can readily do so by using the equation,

$$mrt = 140 - t_a$$

where t_a is the comfort air temperature as determined from the design chart.

The load on the heating boiler is equal to the sum of heat input to the room plus losses from rear face of the panel plus losses from piping. Energy input to the room from the panel face is Q_pA_p. Losses from the rear of the panel depend on the amount of insulation used and hence can vary widely with the method of installation. In most cases, however, such losses will be less than 5% of the total energy input to the room. If the rear of the panel dissipates energy to a heated space this quantity should not be included under "losses" since it serves to reduce the required energy input to the other room; in such cases the energy loss from the rear surface, expressed in Btu/(hr)(sq ft) should be added to the design rating of the panel when determining the required flow rate or temperature difference.

SUMMARY

The method of completing a panel design can be summarized as follows:—

Select the design outside temperature, t_o (paragraph a, page 7).

Select the maximum panel surface temperature, t_p (paragraph b, page 7).

Determine the ventilation rate, V (paragraph c, page 8).

Calculate the equivalent overall coefficient U_e (paragraph d, page 8).

Refer to proper Geometry Chart and find the ventilation correction factor, V_c and the geometry correction factor, K (pages 17 to 21).

Refer to proper Panel Design Chart and find the percent of room surface to be heated, the panel rating (Q_p), and the design value of comfort air temperature, t_a (pages 17 to 21).

Select from Table I, II, or III (pages 53 and 54) a tube size and spacing for use in panel coil.

Select a temperature drop (Δt) of hot water passing through panel.

Refer to Flow Rate Chart (page 52) and find the gpm of hot water required for the panel.

Chapter III: NUMERICAL EXAMPLE

A room 40′ x 40′ x 10′ is to be heated by means of a ceiling panel operating at 120°F surface temperature when the outside air temperature is -10°F. Mechanical ventilation provides 333 cubic feet per minute of untempered outside air. The temperature drop of hot water passing through the panel is taken as 10°F. Areas and overall coefficients of heat transfer of the various surfaces are as follows:

Floor:	$A_f = 1600$	$U_f = 0.15$
Inside Partition:	$A_i = 900$	$U_i = 0$
Exterior Wall:	$A_w = 400$	$U_w = 0.10$
Double Windows:	$A_g = 300$	$U_g = 0.45$

Unheated ceiling area is estimated by taking the panel area as 20% of the total room surface and subtracting this value from the total ceiling area:

$$A_c = 1600 - 0.2 \times 4800 = 1600 - 960 = 640 \qquad U_c = 0.175$$

The total unheated room area is equal to $0.8 \times 4800 = 3840$

Then by equation 1,

$$U_e = \frac{0.45 \times 300 + 0.10 \times 400 + 0 \times 900 + 0.175 \times 640 + 0.15 \times 1600}{3840} = \frac{527}{3840} = 0.137$$

The room volume is 40′ x 40′ x 10′ = 16000 cubic feet so the ventilation rate, V, is equal to

$$\frac{333 \times 60}{16,000} = 1.25 \text{ air changes per hour}$$

Solution

1. *Turn to the Geometry Chart for a room with 10′ ceiling (page 19).*

Enter the chart at $W = 40'$, rise to $L = 40'$, then move horizontally to intersect curve for $V = 1.25$. From this intersection rise to read $V_c = 4.2$, or move horizontally left to find $K = 3.0$. (This example is shown on the Geometry Chart, page 19.)

2. *Refer to the Design Chart for ceiling panel with $t_p = 120°F$ and $t_o = -10°F$ (page 31).*

Enter the V_c and U_e scales at 4.2 and 0.137 respectively and extend the corresponding lines to intersection at the design point. From this point move horizontally right to read the optimum comfort inside air temperature as t_a = 63.7°F, or move up in a direction parallel to the rating line to intersect the panel rating scale at Q_p = 80.7 Btu/(hr)(sq ft). Likewise, from the design point move vertically up to the line for K = 3.0 and from this intersection move horizontally left to the scale at edge of chart to read 54% of the ceiling as the required panel area. Since the total ceiling area is 1600 square feet, the panel area, A_p, is 0.54 $\times$ 1600 = 867 square feet.

The accuracy of the above solution can now be checked by re-calculating U_e with A_c = 1600 − 867 = 733 and hence,

$$U_e = \frac{0.45 \times 300 + 0.10 \times 400 + 0 \times 900 + 0.175 \times 733 + 0.15 \times 1600}{4800 - 867} = \frac{543}{3933} = 0.1375$$

Referring again to the panel design chart, the difference between U_e = 0.137 and U_e = 0.1375 is seen to be negligible, hence the panel area as determined from the first trial is correct. Notwithstanding the fact that the originally estimated value of A_p (960 square feet) differs by 10% from the calculated value (867 square feet) the chart value has an accuracy of better than 99½%.

3. *To determine the size and spacing of copper tube for use in this panel, refer to Table III (page 54) for $t_p = 120°F$.*

Enter the table in the panel rating column at Q_p = 80 and move horizontally over to read the required mean water temperature for each of the nine tabulated tubing arrangements. Thus if ⅜″ nominal copper tube is used on 4″ centers the mean water temperature will be 154°F and with a 10°F temperature drop of the water passing through the panel the entering water temperature will have to be 154 + 5 = 159°F.

4. *To determine the gallons per minute which must pass through this panel.*

Enter the flow rate chart (page 52) at A_p = 8.67, rise to Q_p = 80.7, move left to Δt = 10°F and rise to read the answer as 0.139 gpm. But the actual panel

area is 100×8.67 so the corresponding actual flow rate is $100 \times 0.139 = 13.9$ gpm. If the temperature difference were doubled the flow rate would, of course, be halved.

5. The total heating load for this room is $80.7 \times 867 = 70{,}000$ Btu/hr.

To this value must be added any losses to unheated spaces which occur from the rear of the panel or from the piping.

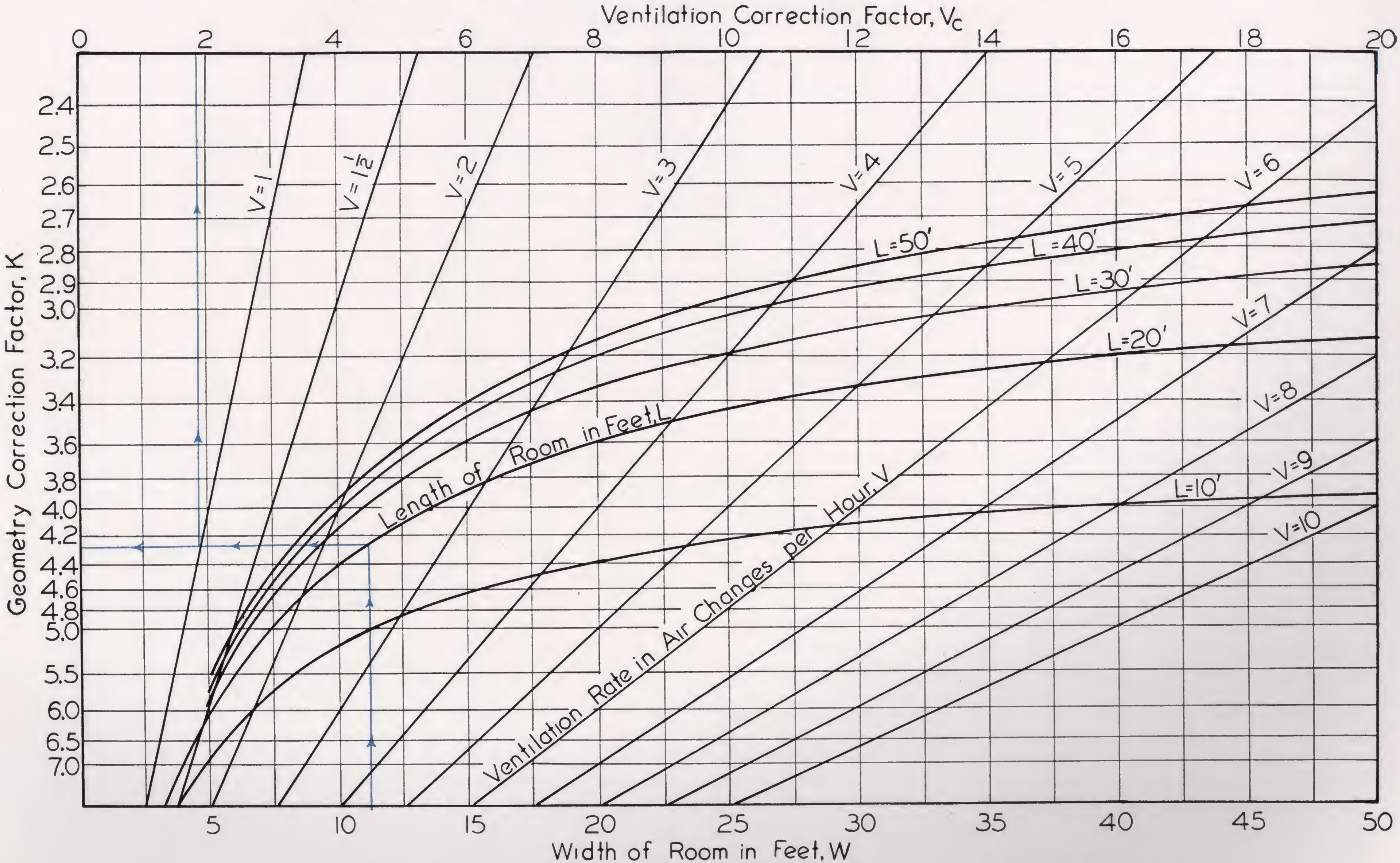
Summarizing, the installation for this room (neglecting losses) would require a 70,000 Btu/hr boiler supplying 13.9 gpm of 159°F water to an 867 square foot panel. Comfort air temperature within the room (for design load) would be 63.7°F and the corresponding mean radiant temperature would be $140 - 63.7 = 76.3$°F.

Chapter IV: CONCLUSION

The design procedure developed in preceding sections is applicable to all types of structures irrespective of climatic, thermal, architectural, or ventilation characteristics. In order to obtain a maximum of clarity in presentation, the numerical example which has been presented was for a simple case involving one room only; the designer will readily visualize the adaptations needed to apply the method to more complex cases. For very unusual structures or for panels having a maximum surface temperature less than 85°F or greater than 120°F the graphs will not apply. In such cases the designer is invited to consult the Research and Development Department of Revere Copper and Brass Incorporated at Rome, New York; insofar as possible every effort will be made — as a service to the contractor and engineer — to provide the additional engineering data required for such cases.

GEOMETRY CHART FOR ROOM WITH 8 FOOT CEILING

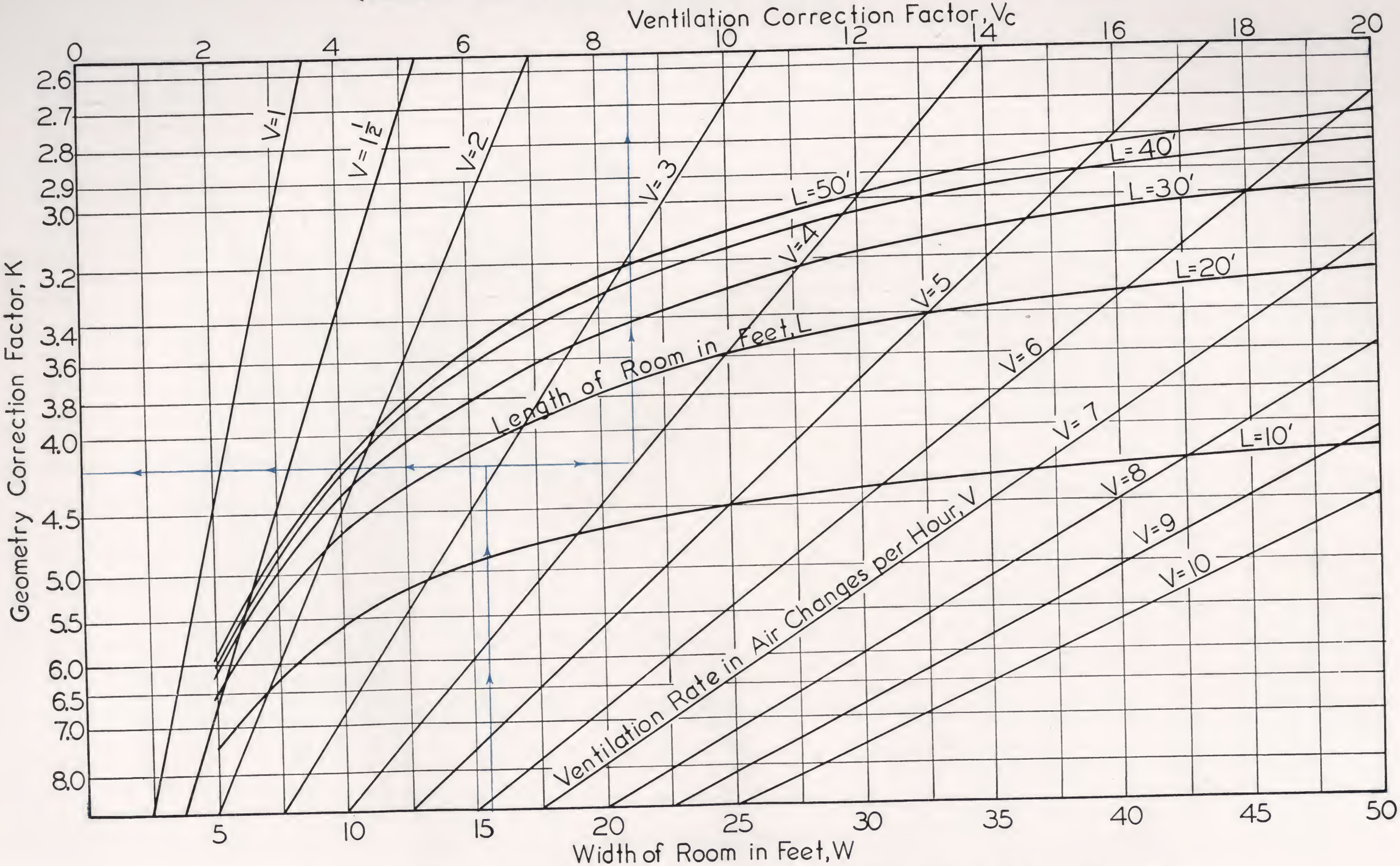
(Values of V_c and K from this chart are for use with Panel Design Chart)



For known dimensions of a room and the Ventilation Rate in Air Changes per Hour, V, the **blue** example line shows the method of finding the Geometry Correction Factor, K, and the Ventilation Correction Factor, V_c

GEOMETRY CHART FOR ROOM WITH 9 FOOT CEILING

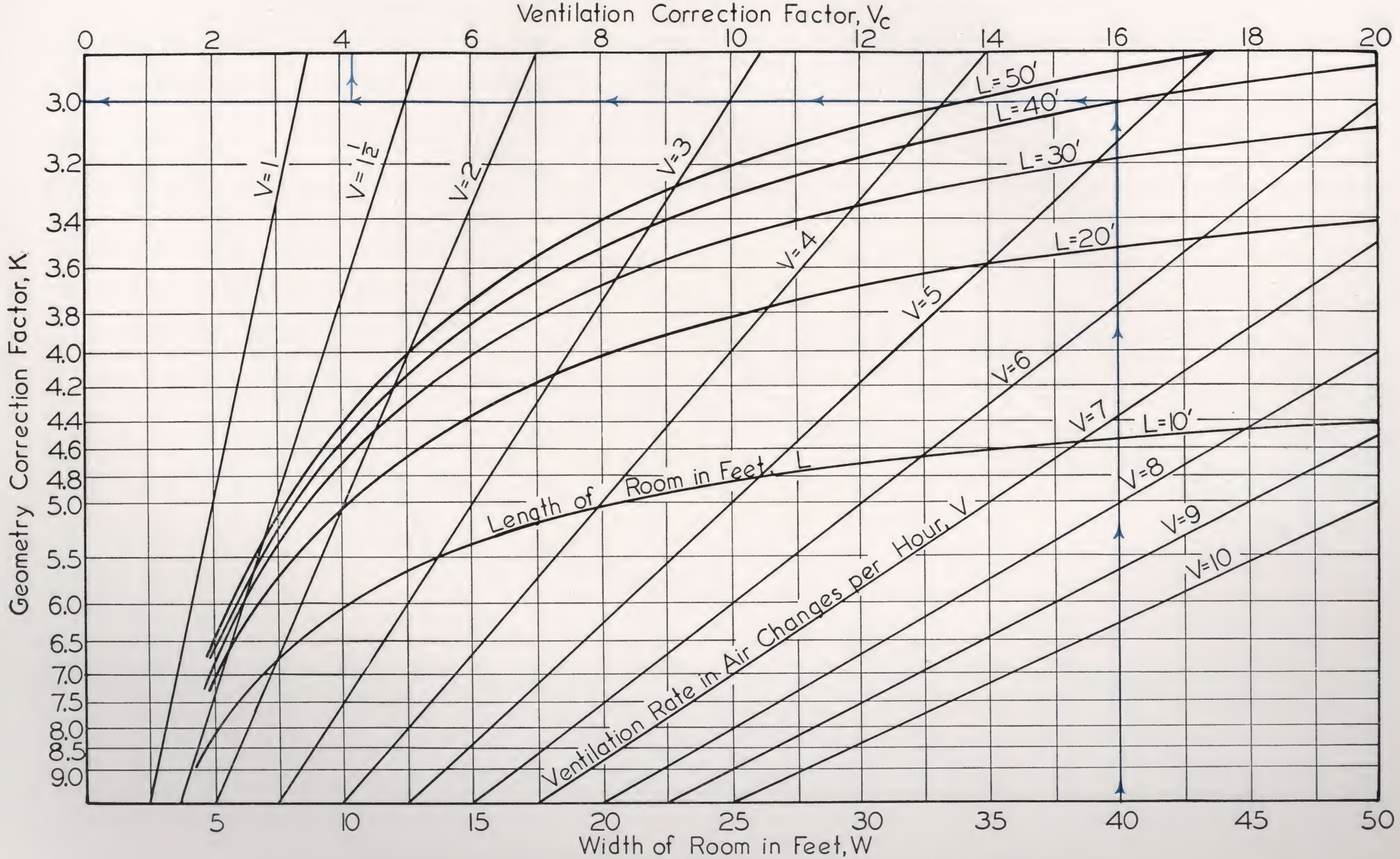
(Values of V_c and K from this chart are for use with Panel Design Chart)



For known dimensions of a room and the Ventilation Rate in Air Changes per Hour, V, the **blue** example line shows the method of finding the Geometry Correction Factor, K, and the Ventilation Correction Factor, V_c

GEOMETRY CHART FOR ROOM WITH 10 FOOT CEILING

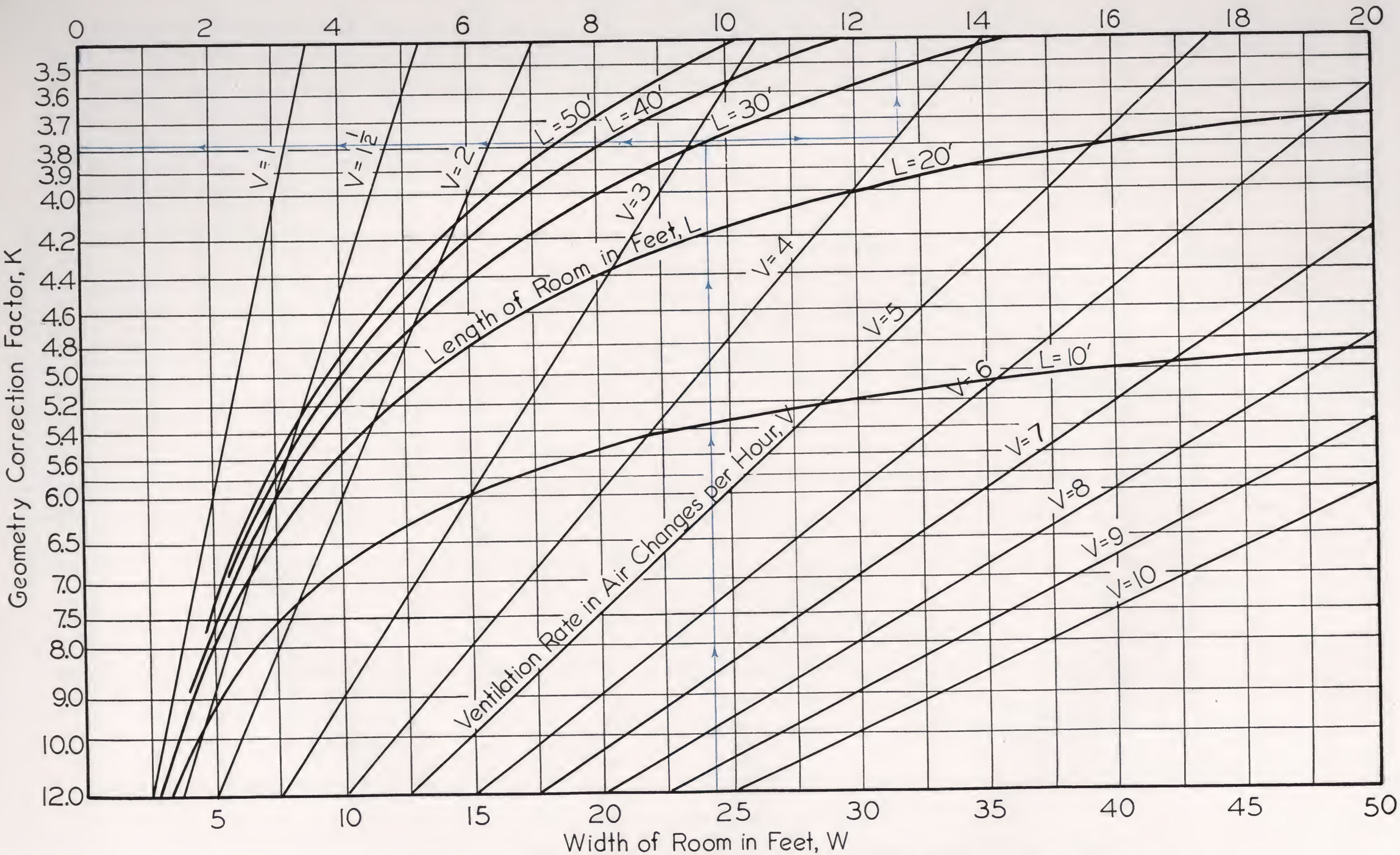
(Values of V_c and K from this chart are for use with Panel Design Chart)



For known dimensions of a room and the Ventilation Rate in Air Changes per Hour, V, the **blue** example line shows the method of finding the Geometry Correction Factor, K, and the Ventilation Correction Factor, V_c

GEOMETRY CHART FOR ROOM WITH 12 FOOT CEILING

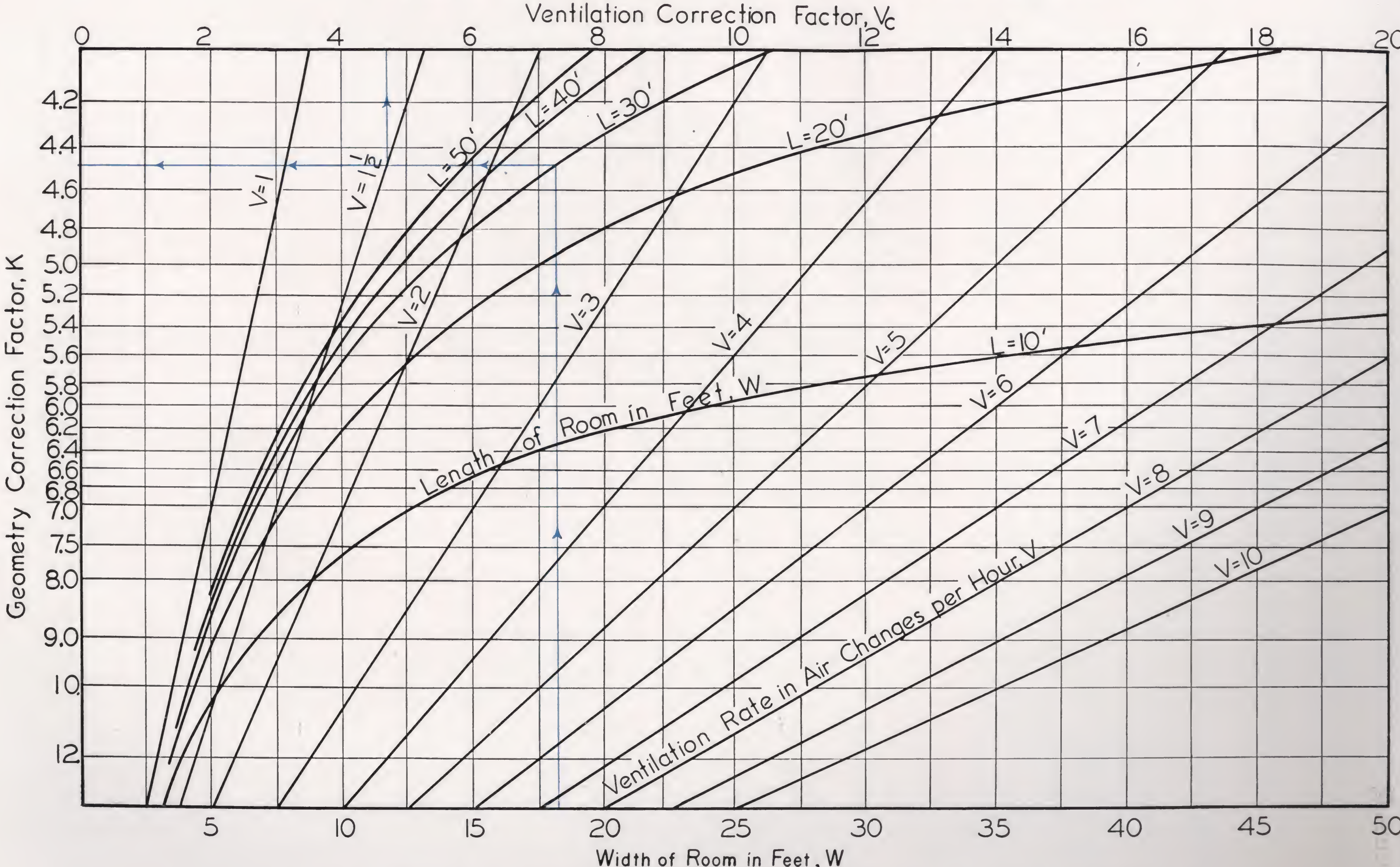
(Values of V_c and K from this chart are for use with Panel Design Chart)



For known dimensions of a room and the Ventilation Rate in Air Changes per Hour, V, the **blue** example line shows the method of finding the Geometry Correction Factor, K, and the Ventilation Correction Factor, V_c

GEOMETRY CHART FOR ROOM WITH 14 FOOT CEILING

(Values of V_c and K from this chart are for use with Panel Design Chart)

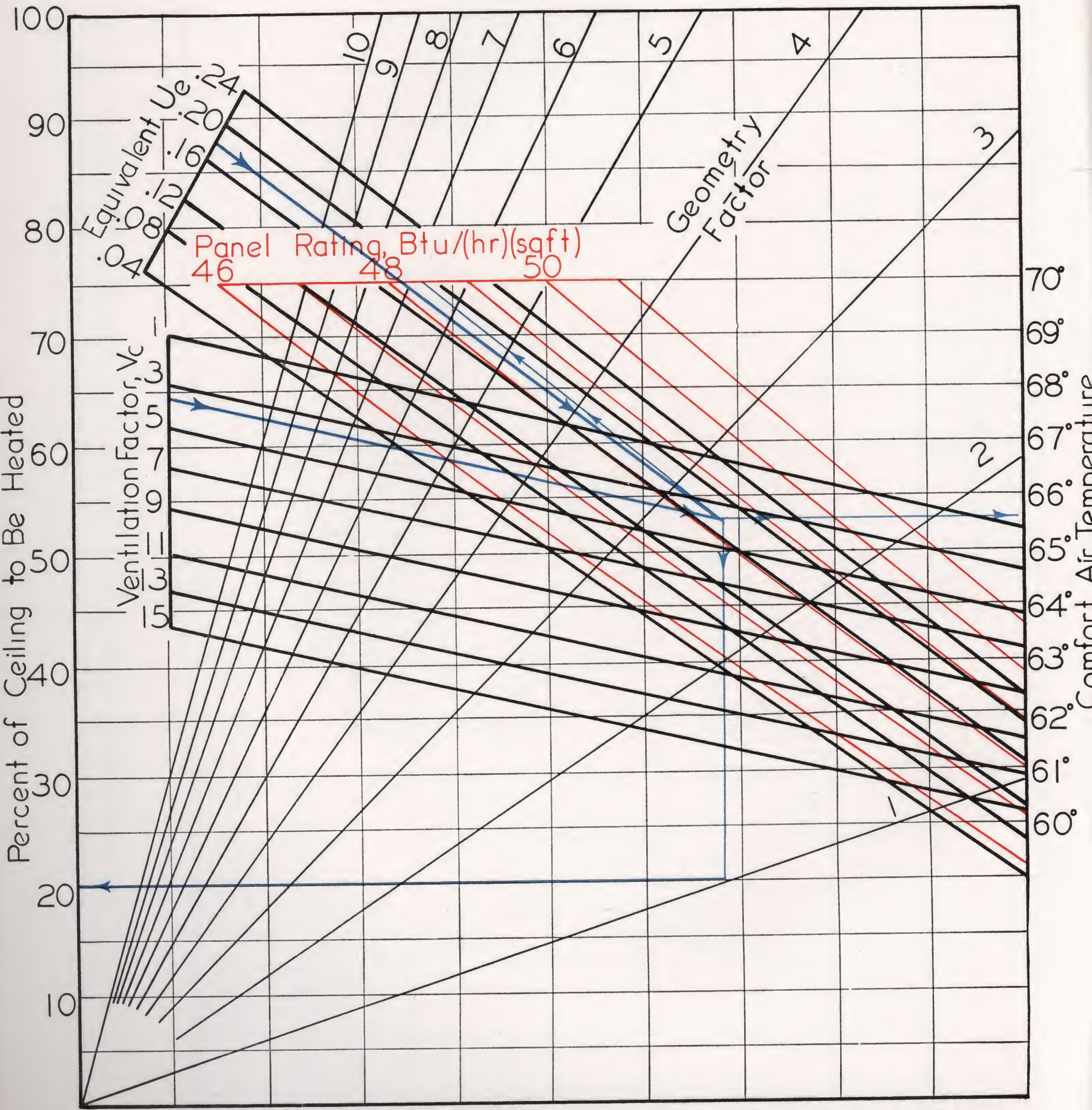


For known dimensions of a room and the Ventilation Rate in Air Changes per Hour, V, the **blue** example line shows the method of finding the Geometry Correction Factor, K, and the Ventilation Correction Factor, V_c

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = + 30°

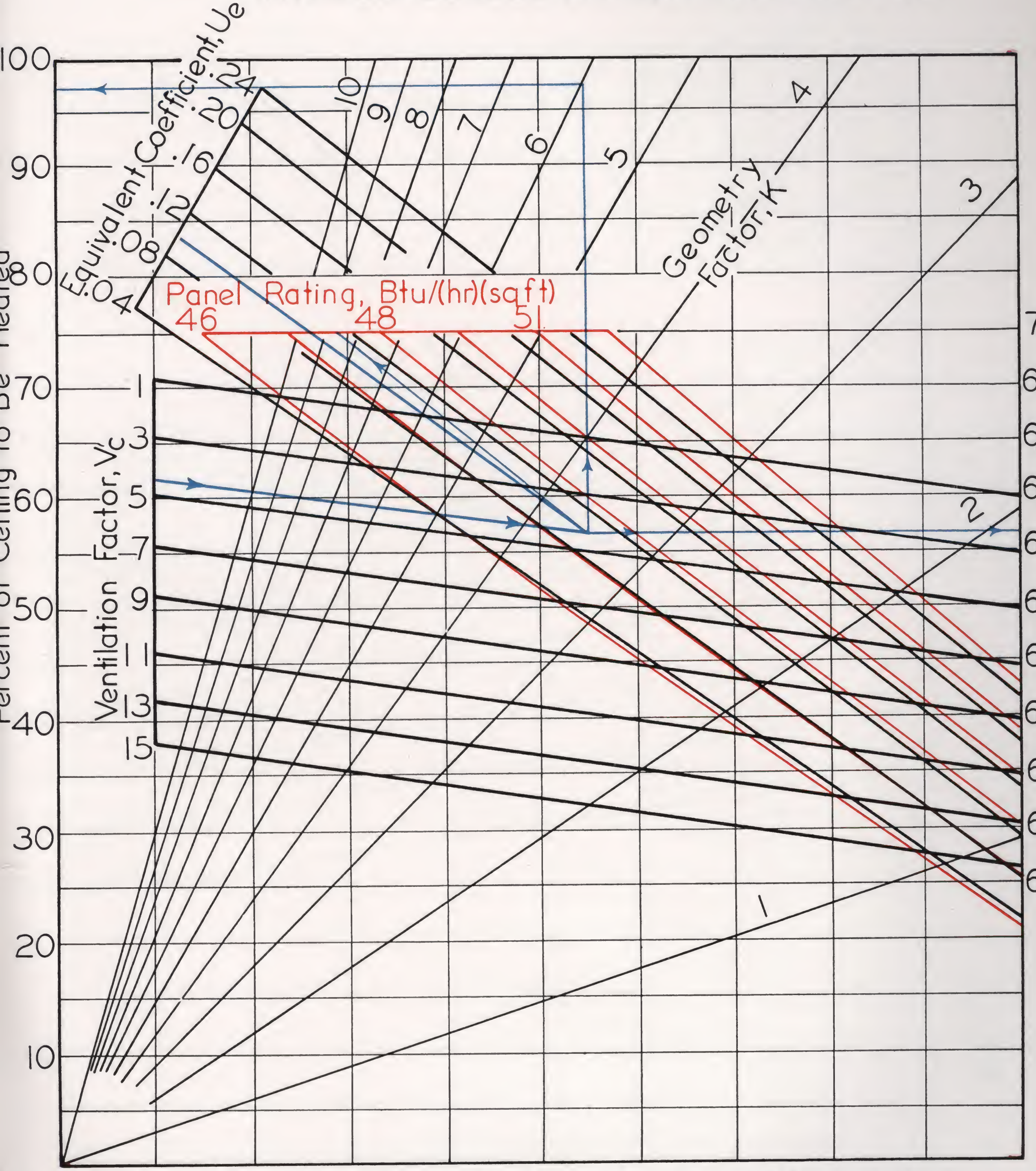


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = +20°

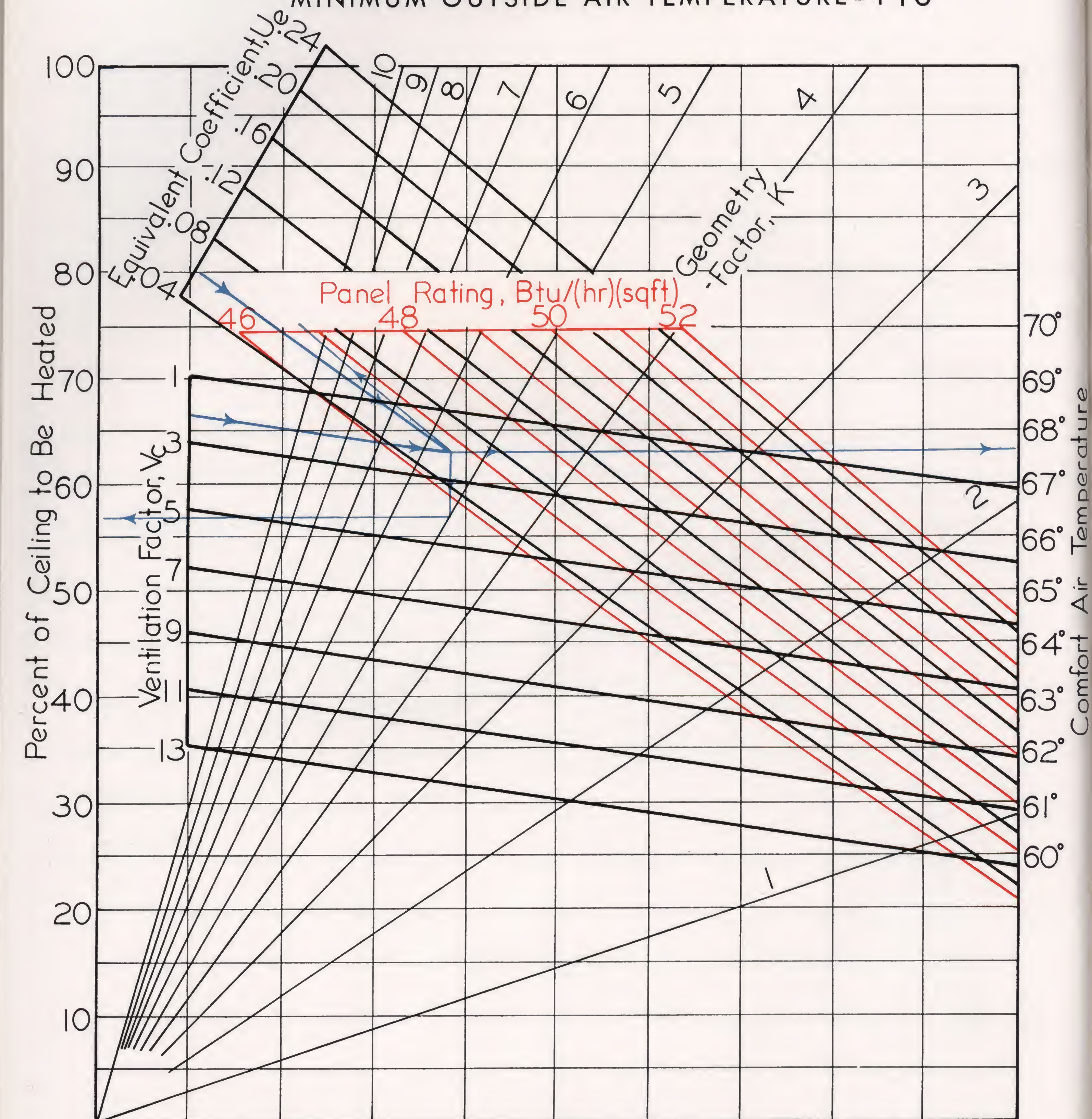


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = +10°

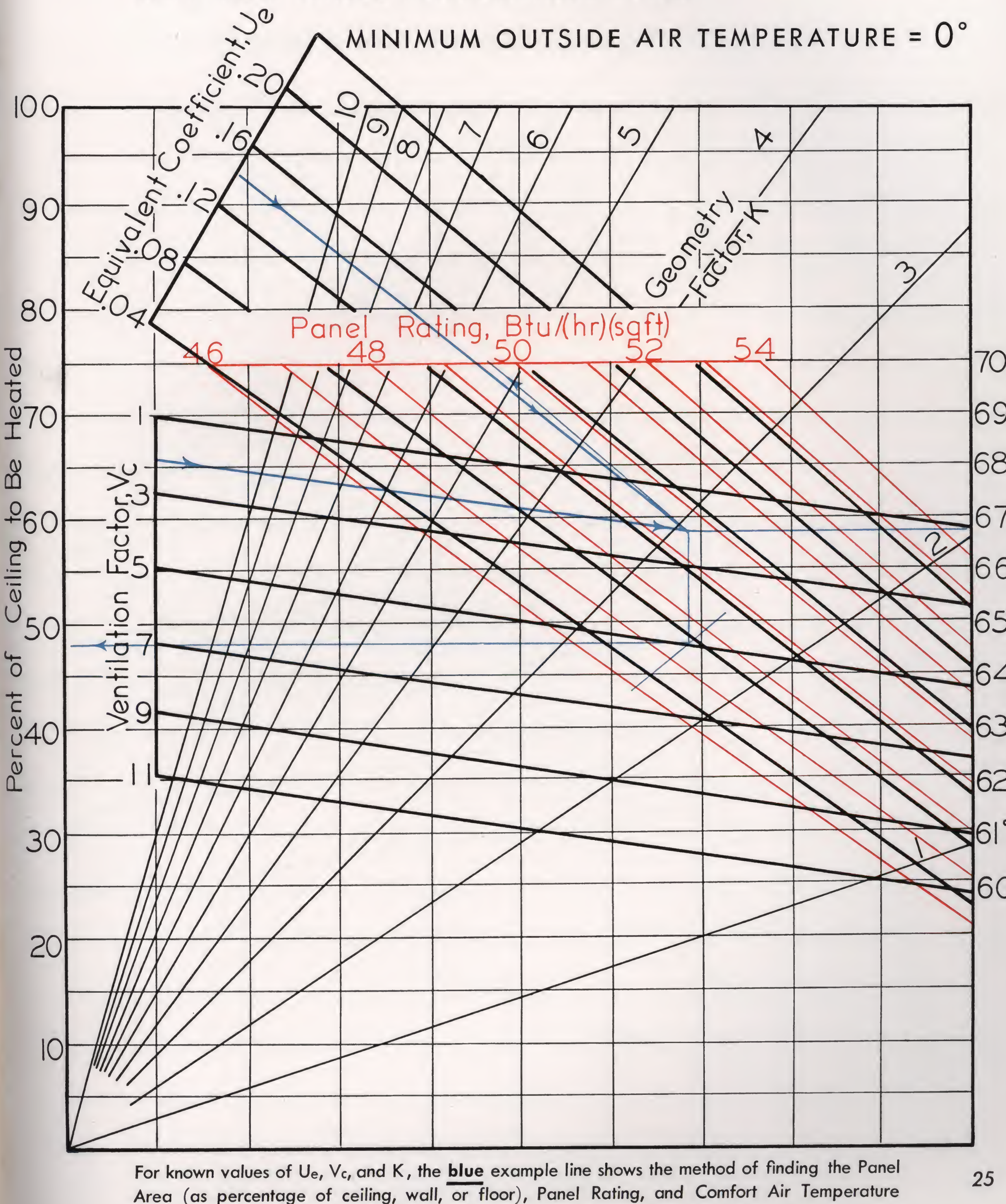


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = 0°

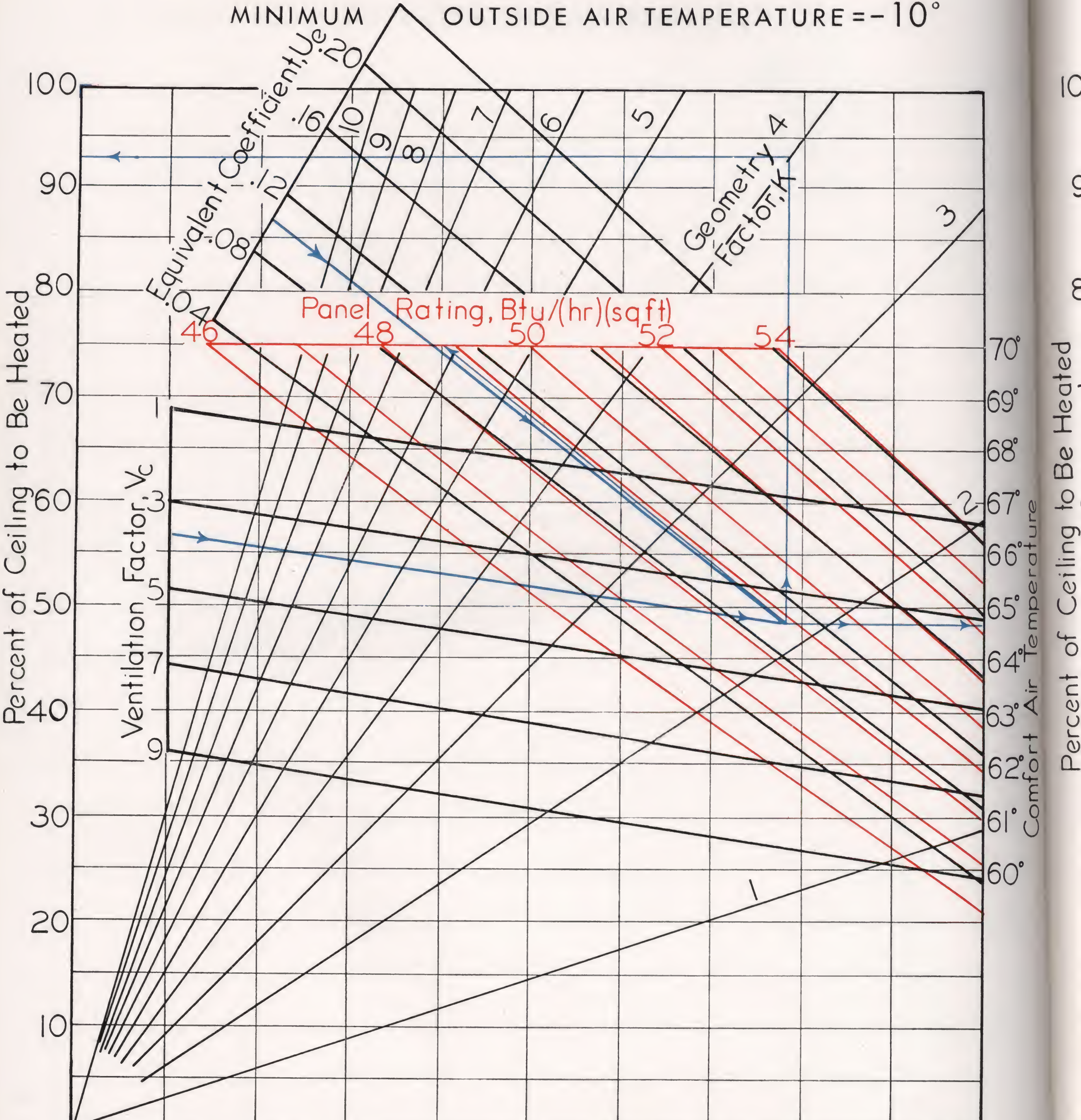


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = -10°

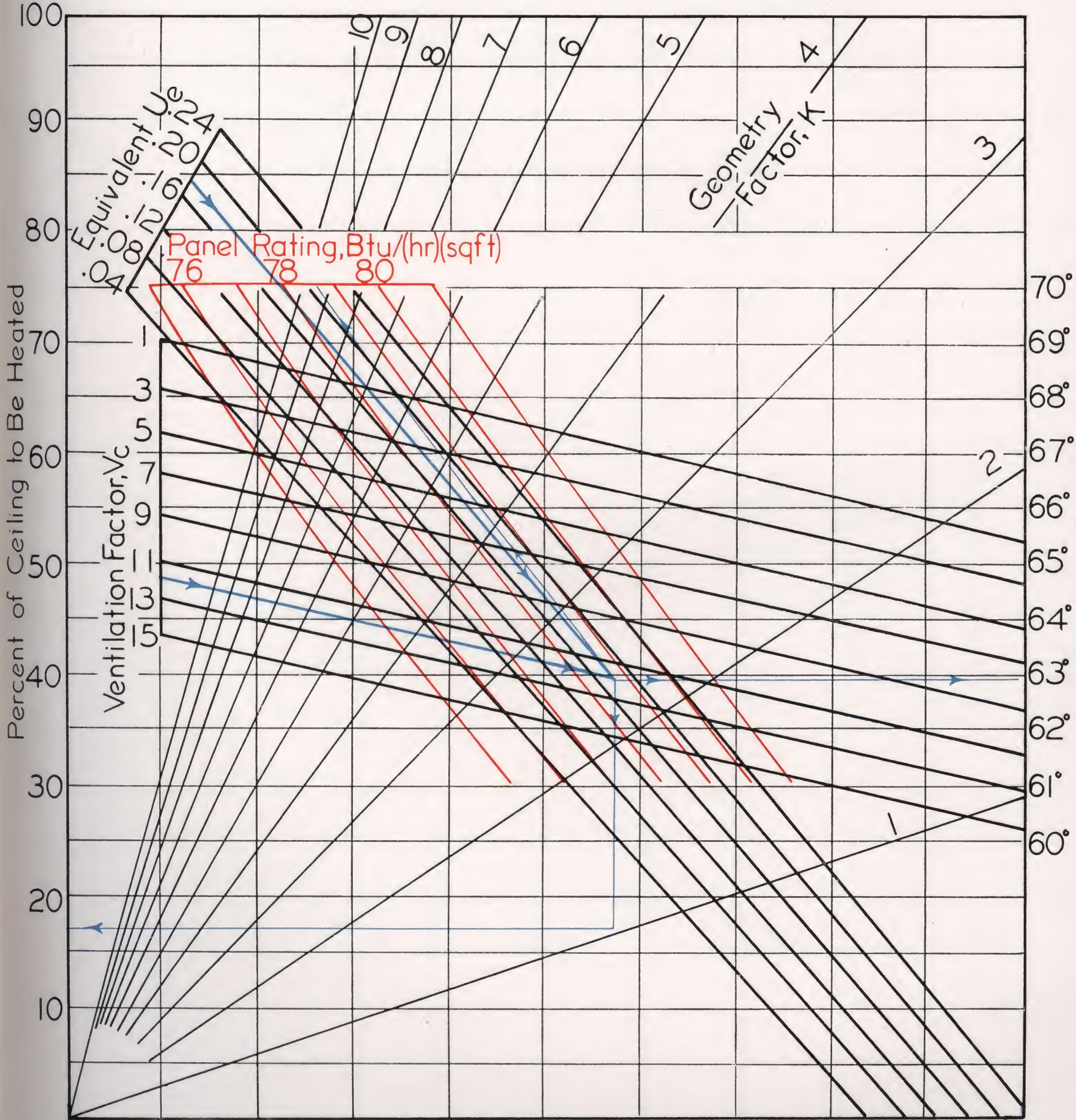


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = +30°

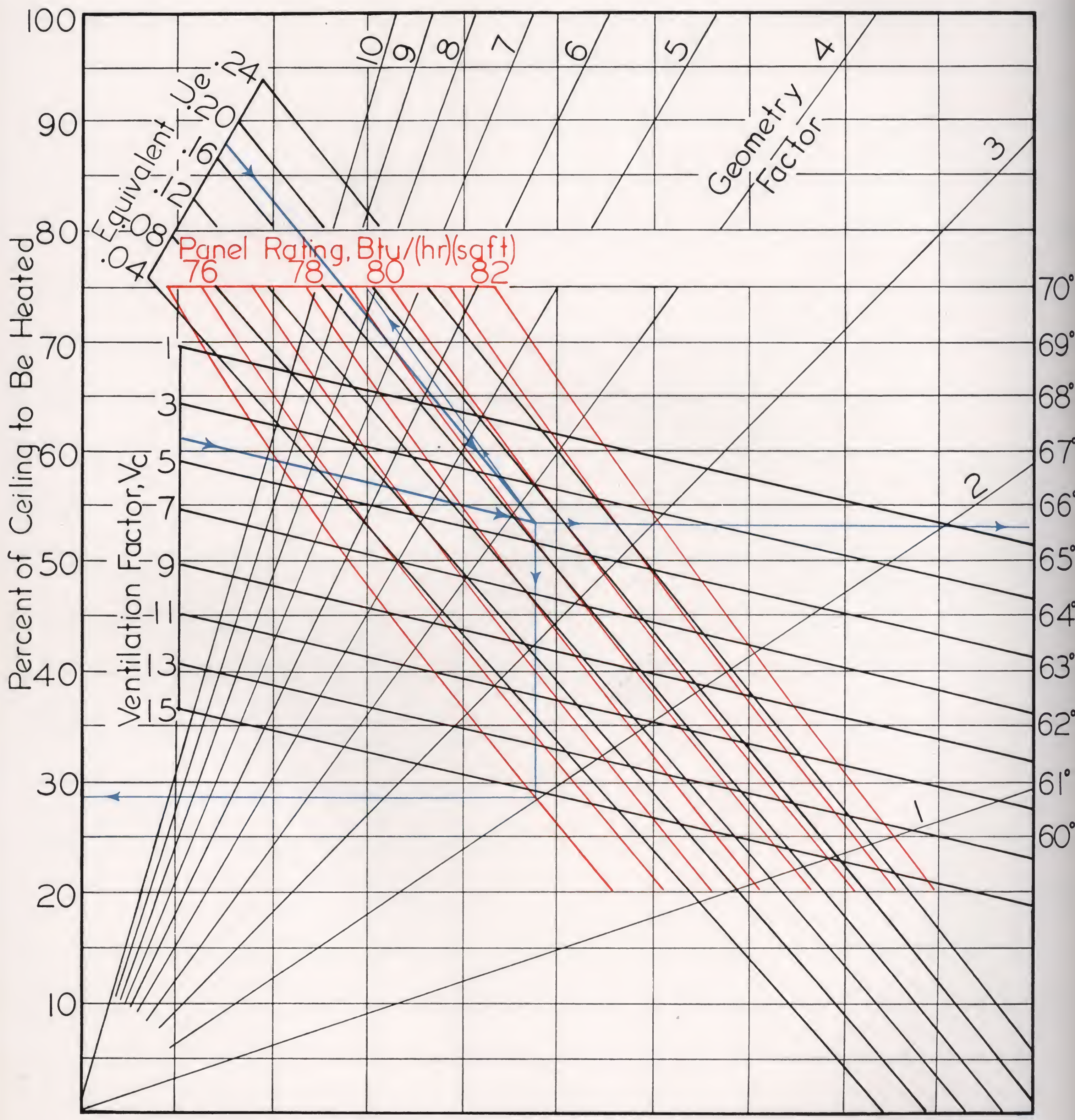


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = + 20°

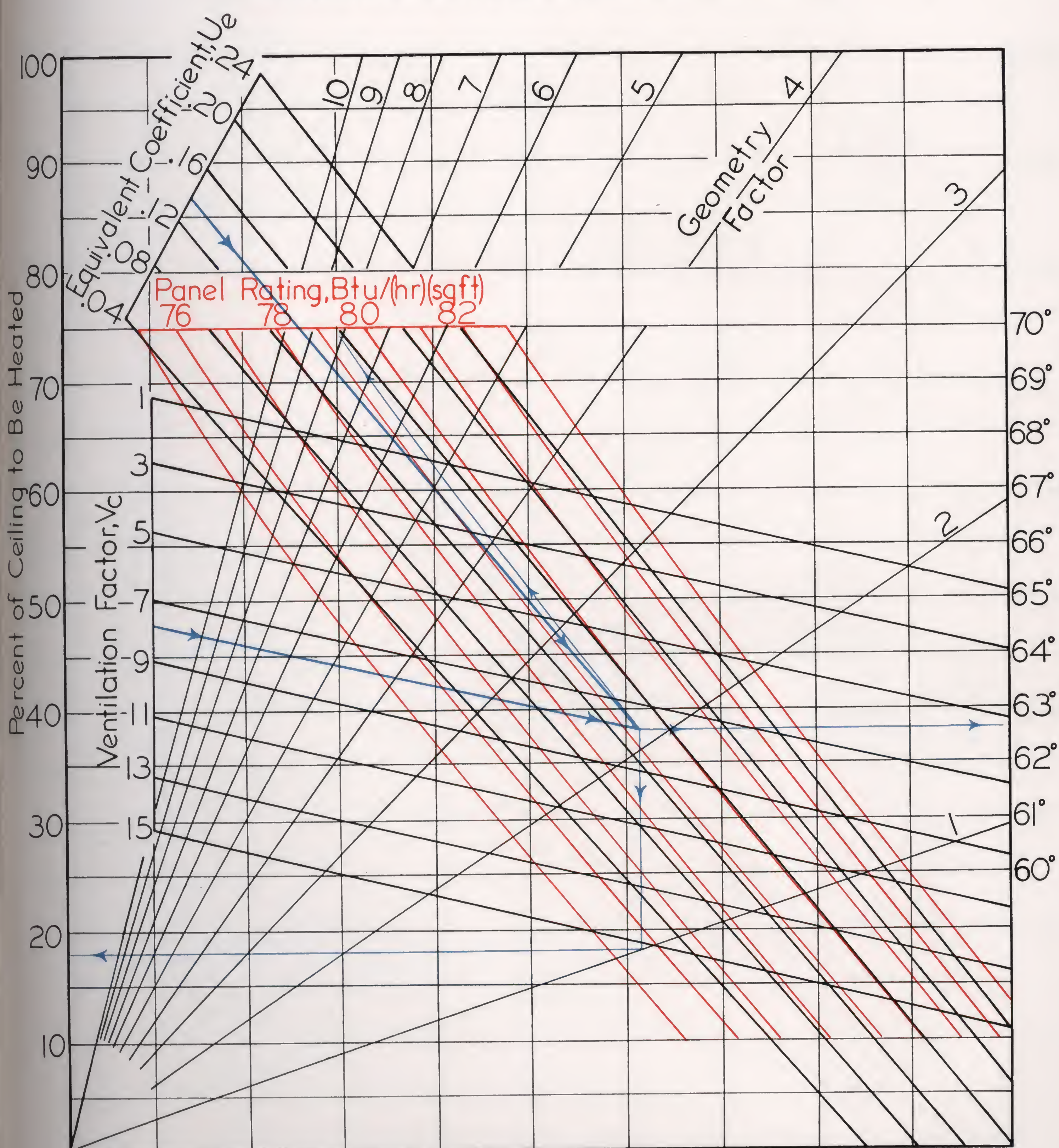


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = +10°

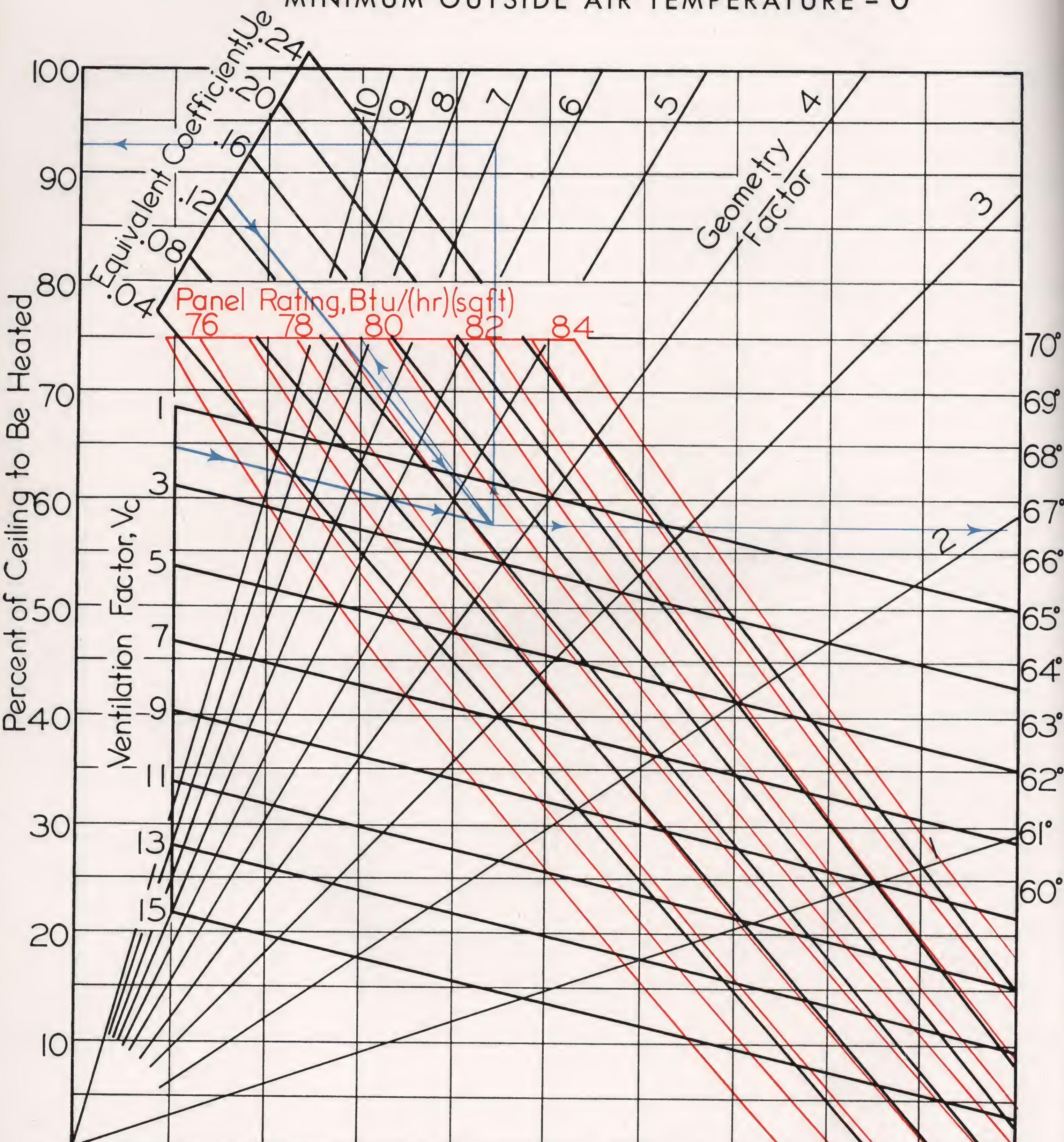


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = 0°

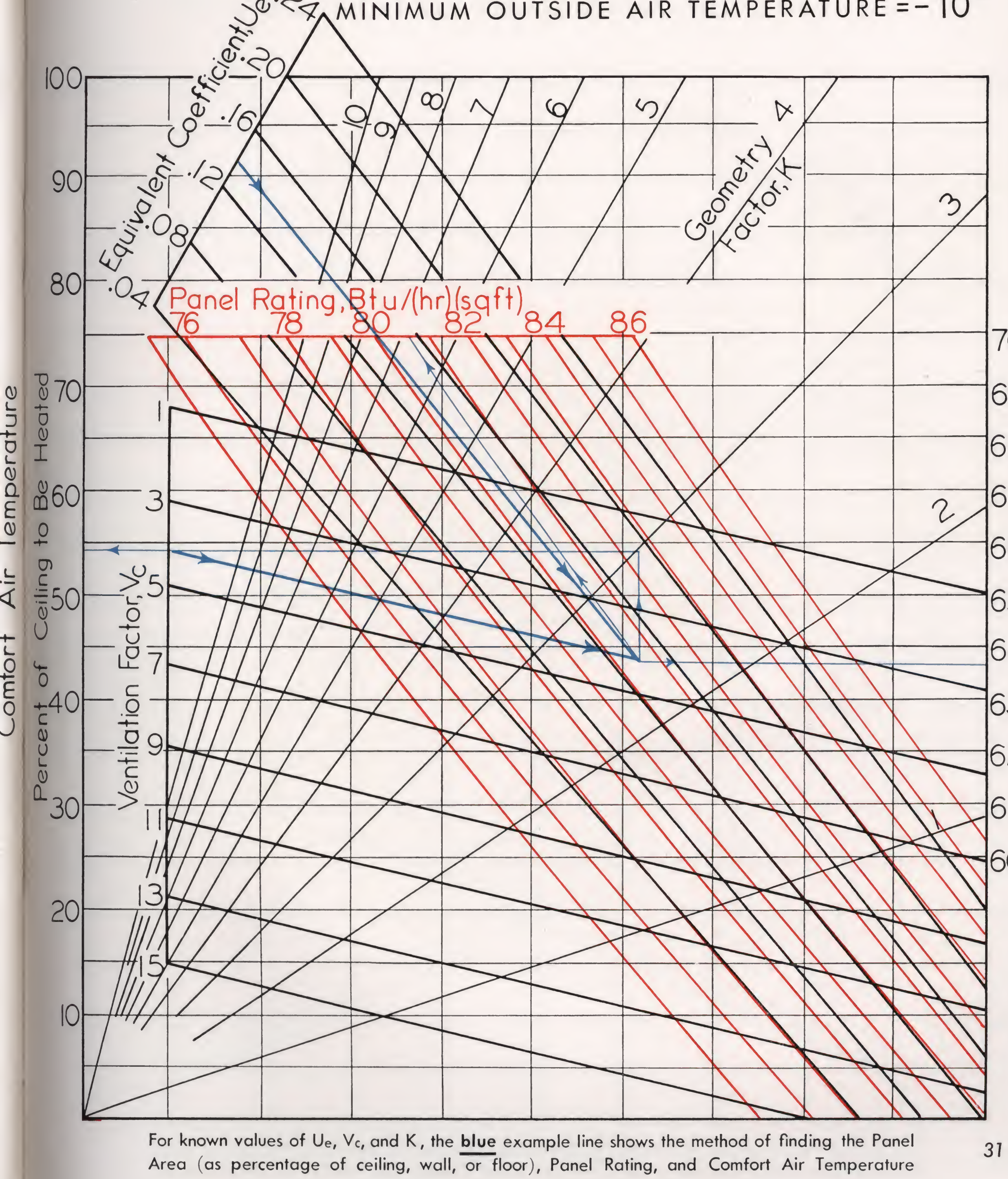


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

CEILING PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = − 10°

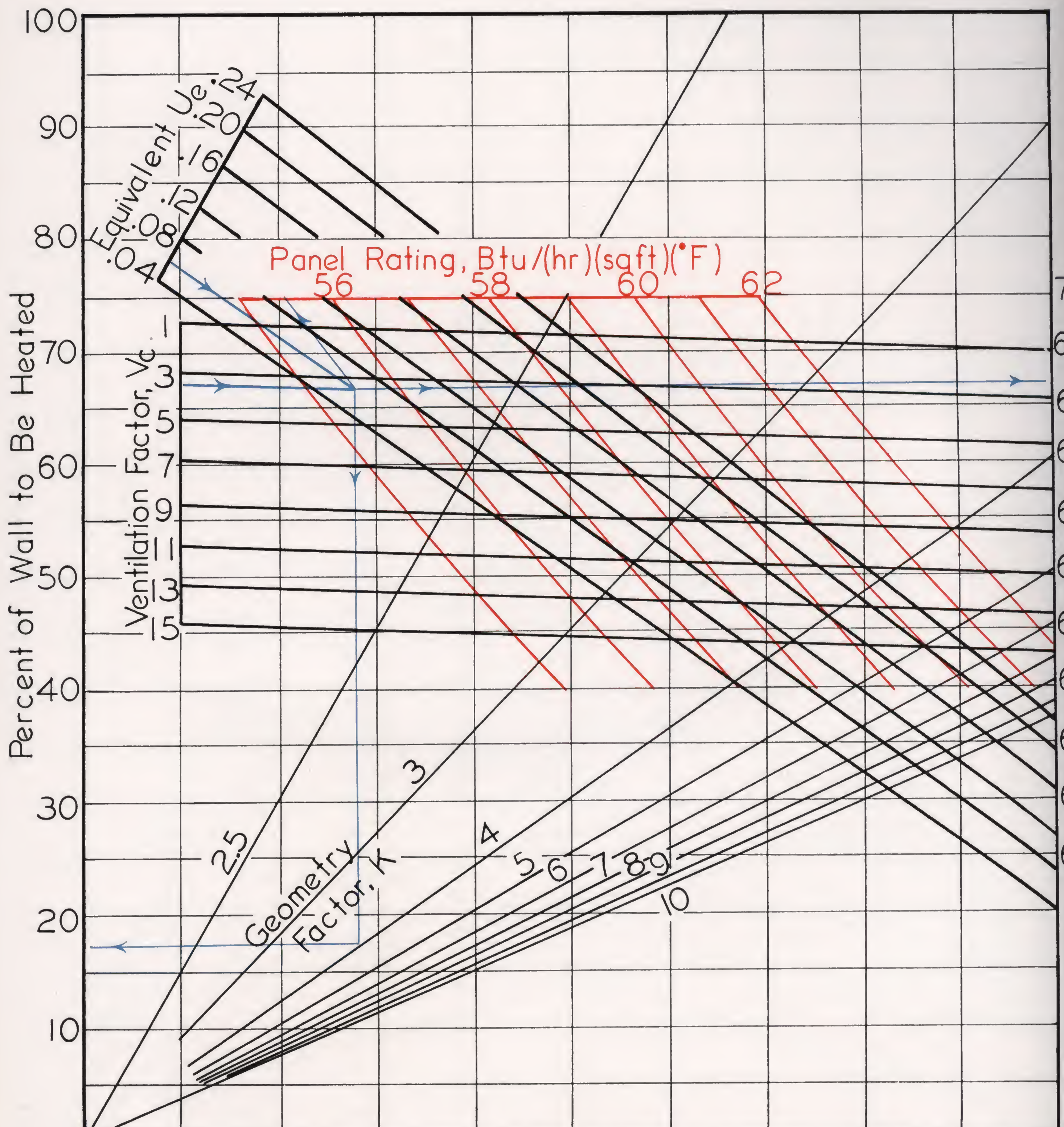


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = +30°

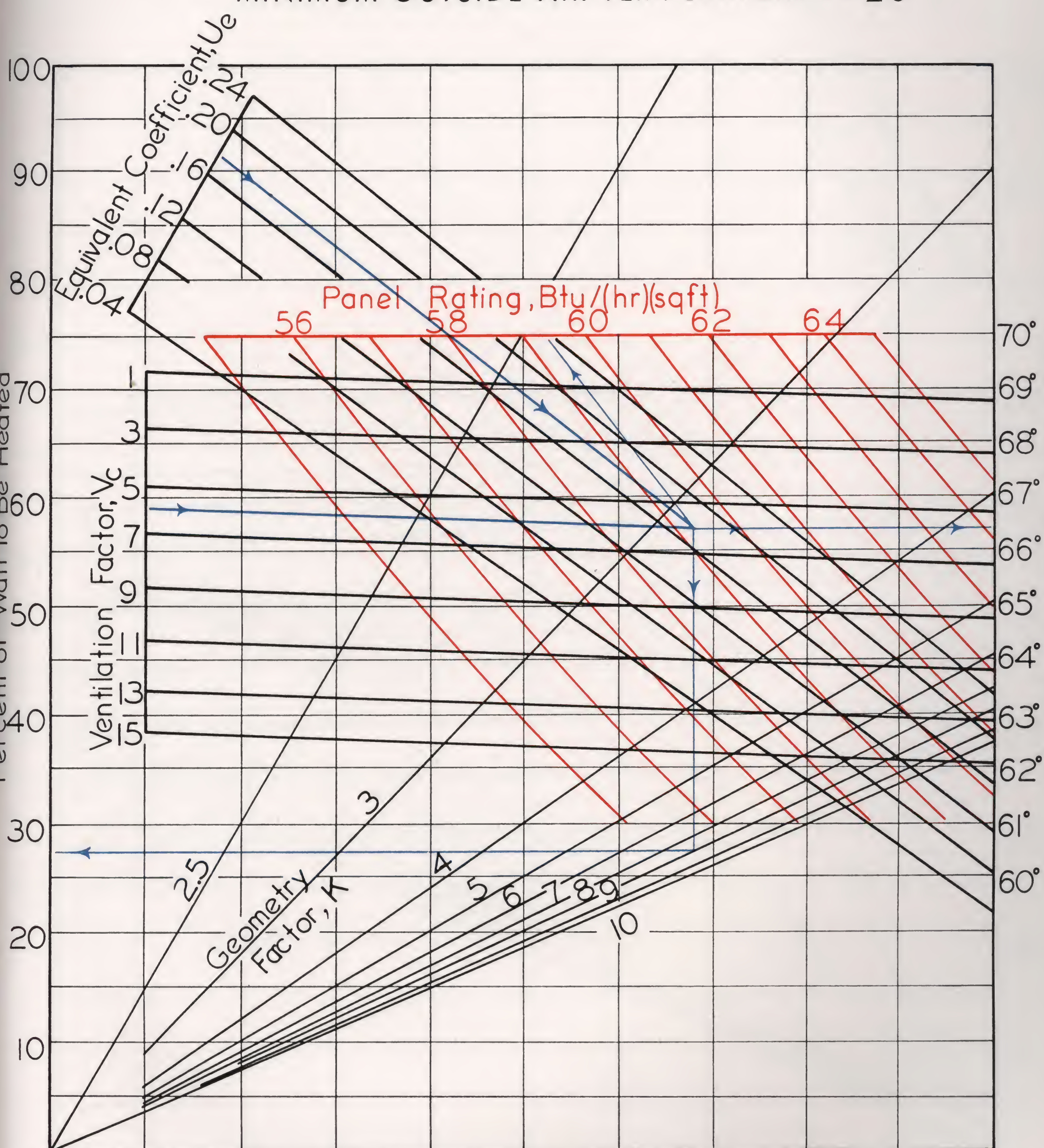


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = + 20°

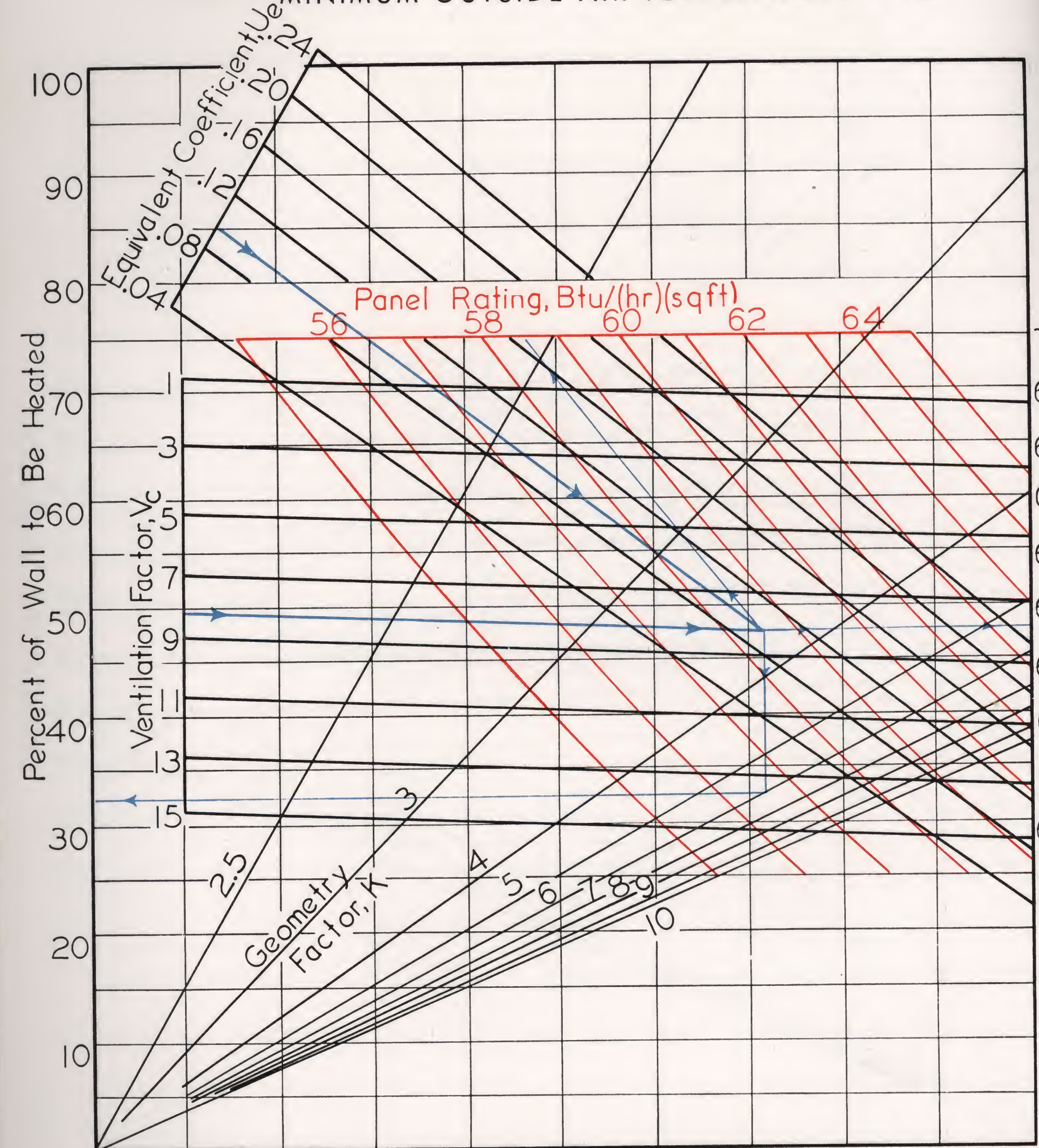


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 100°

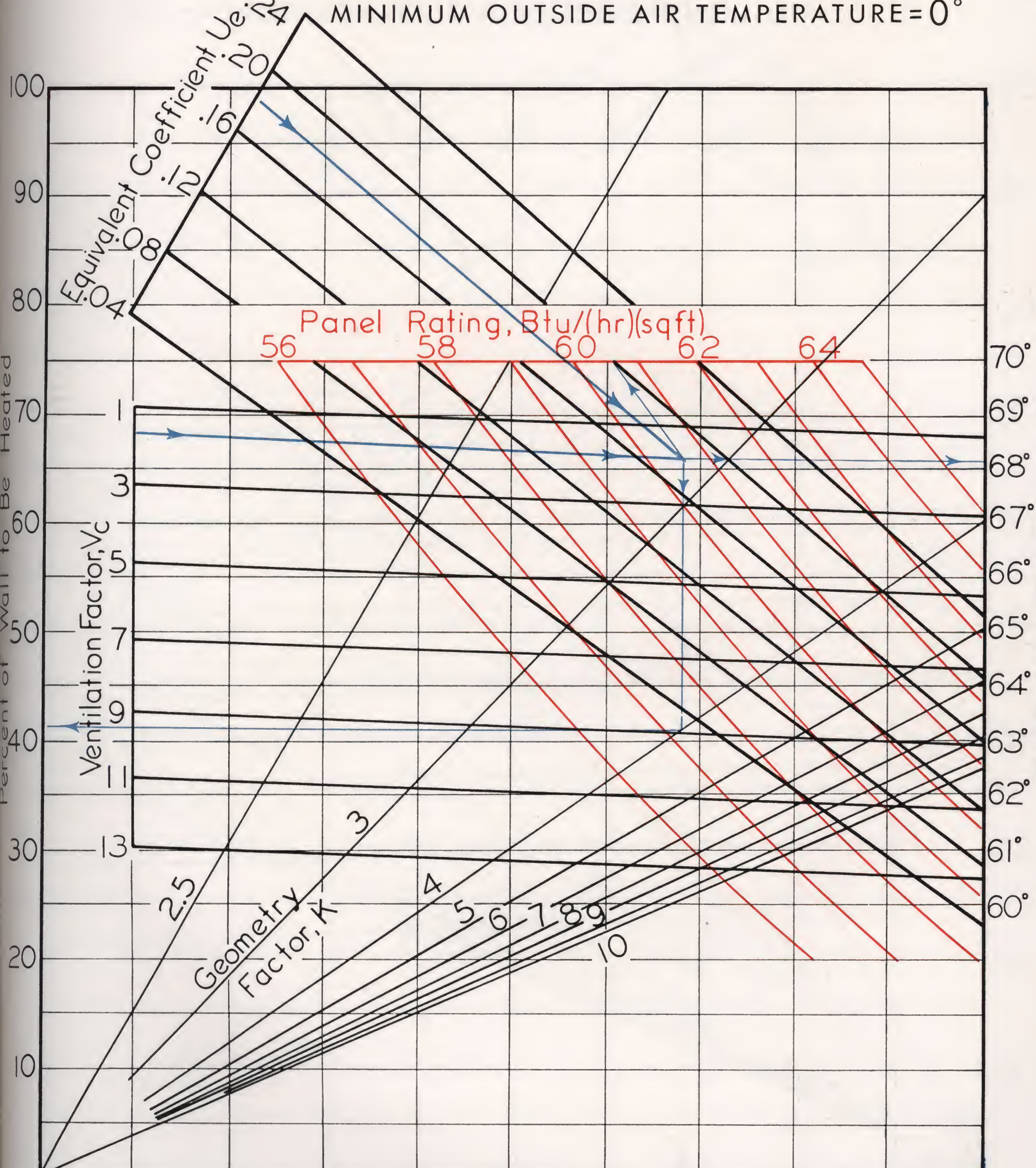
MINIMUM OUTSIDE AIR TEMPERATURE = +10°



For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 100°

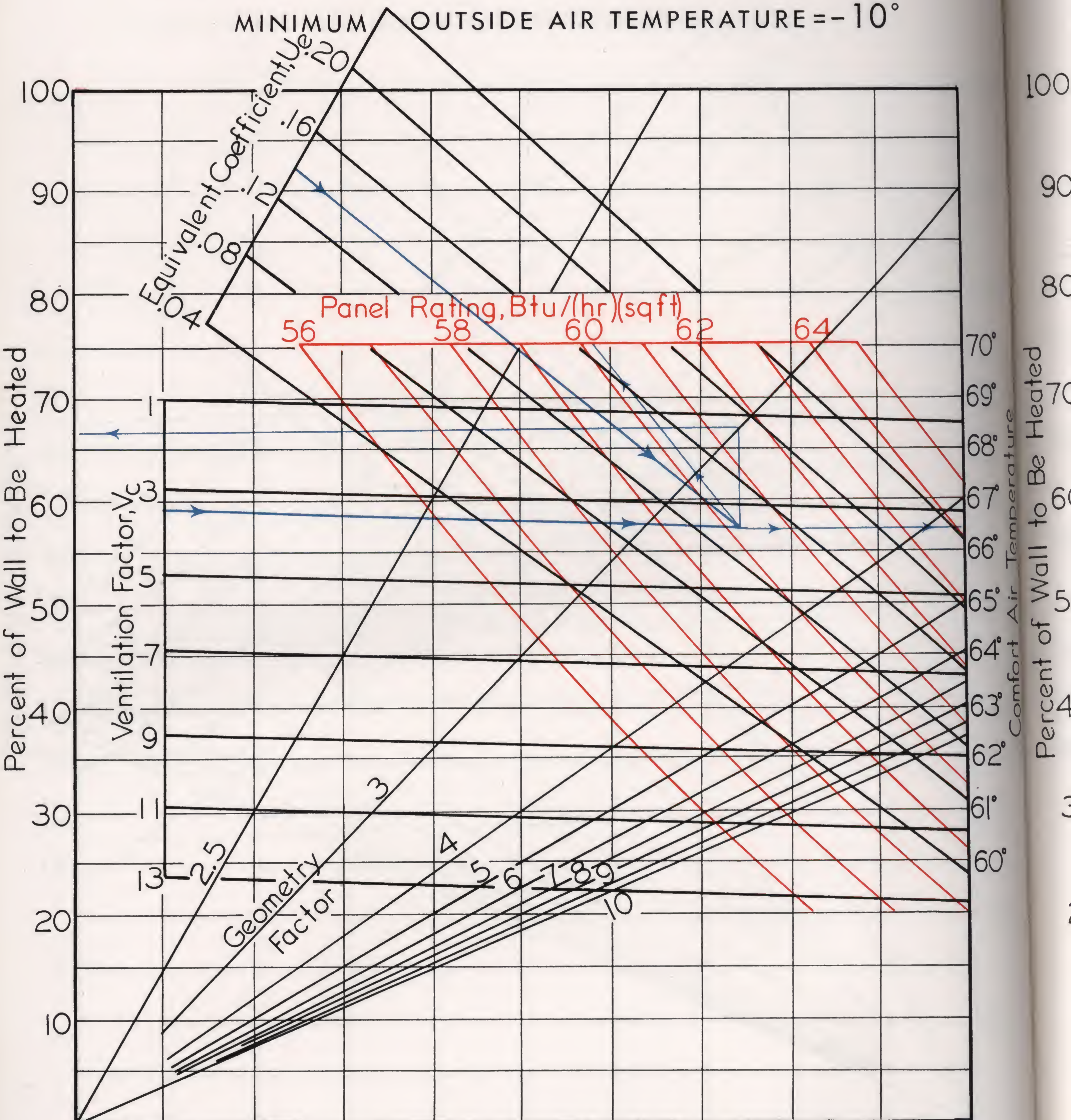


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = −10°

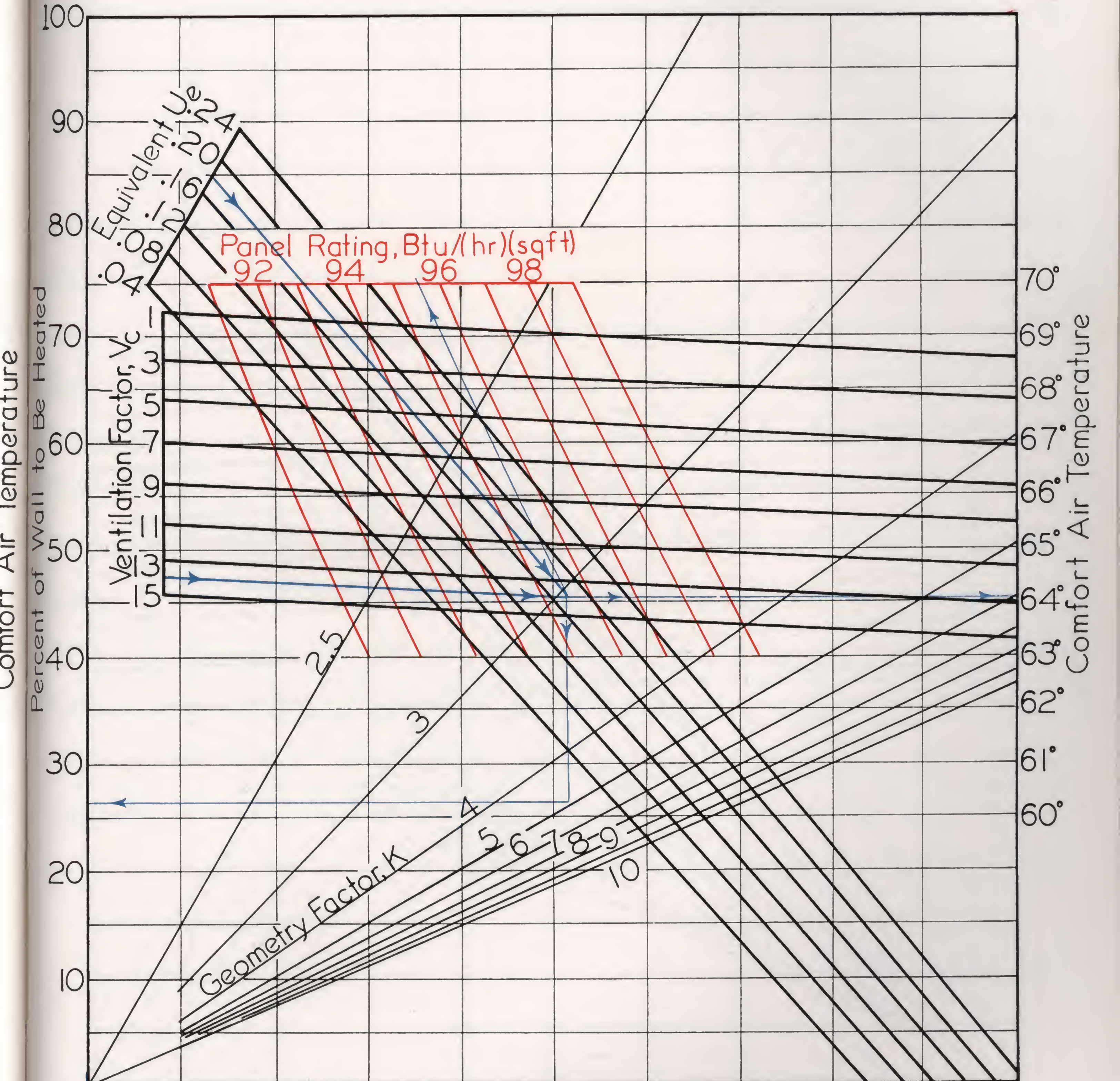


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = +30°

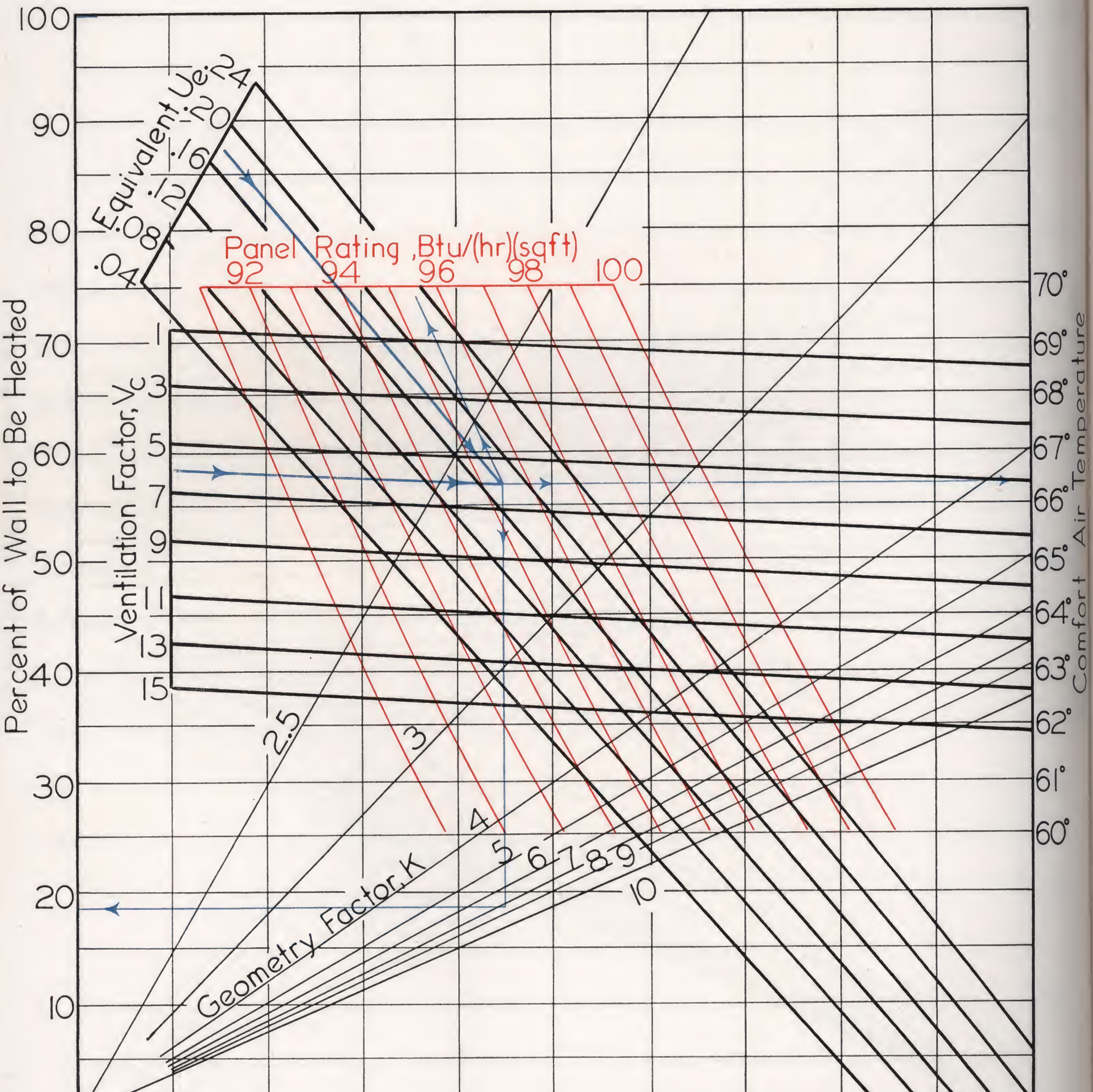


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = + 20°

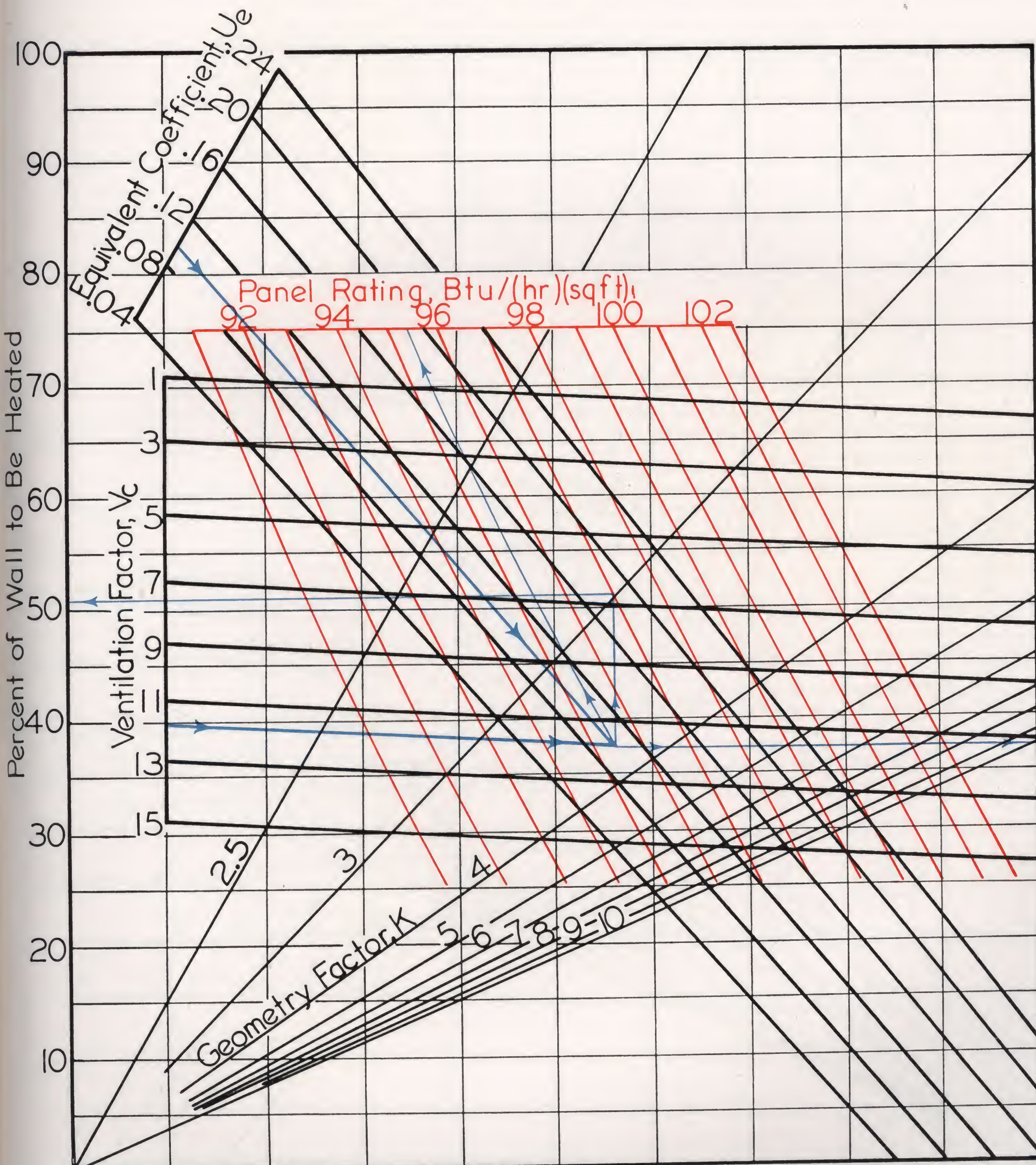


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = +10°

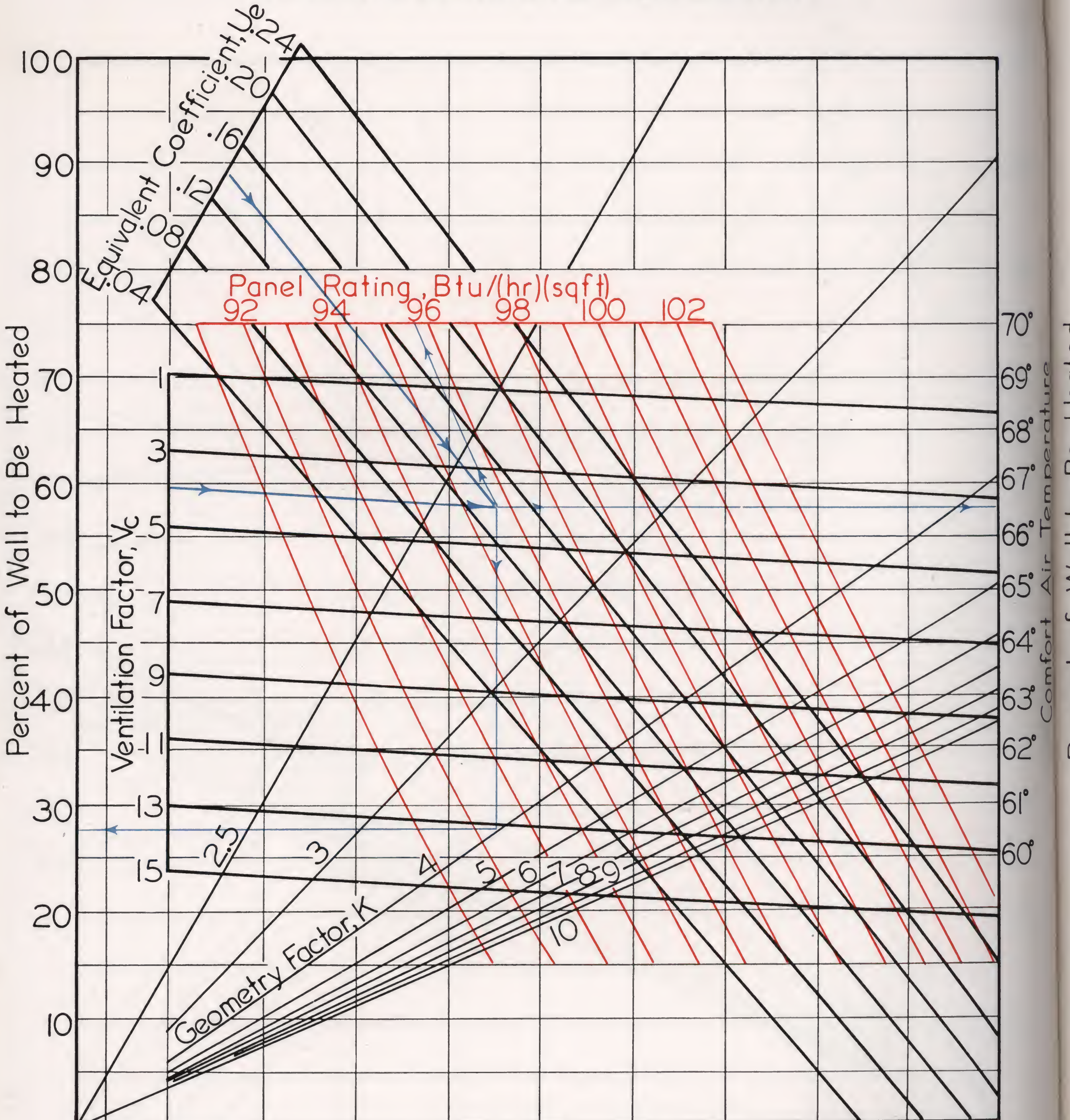


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = 0°

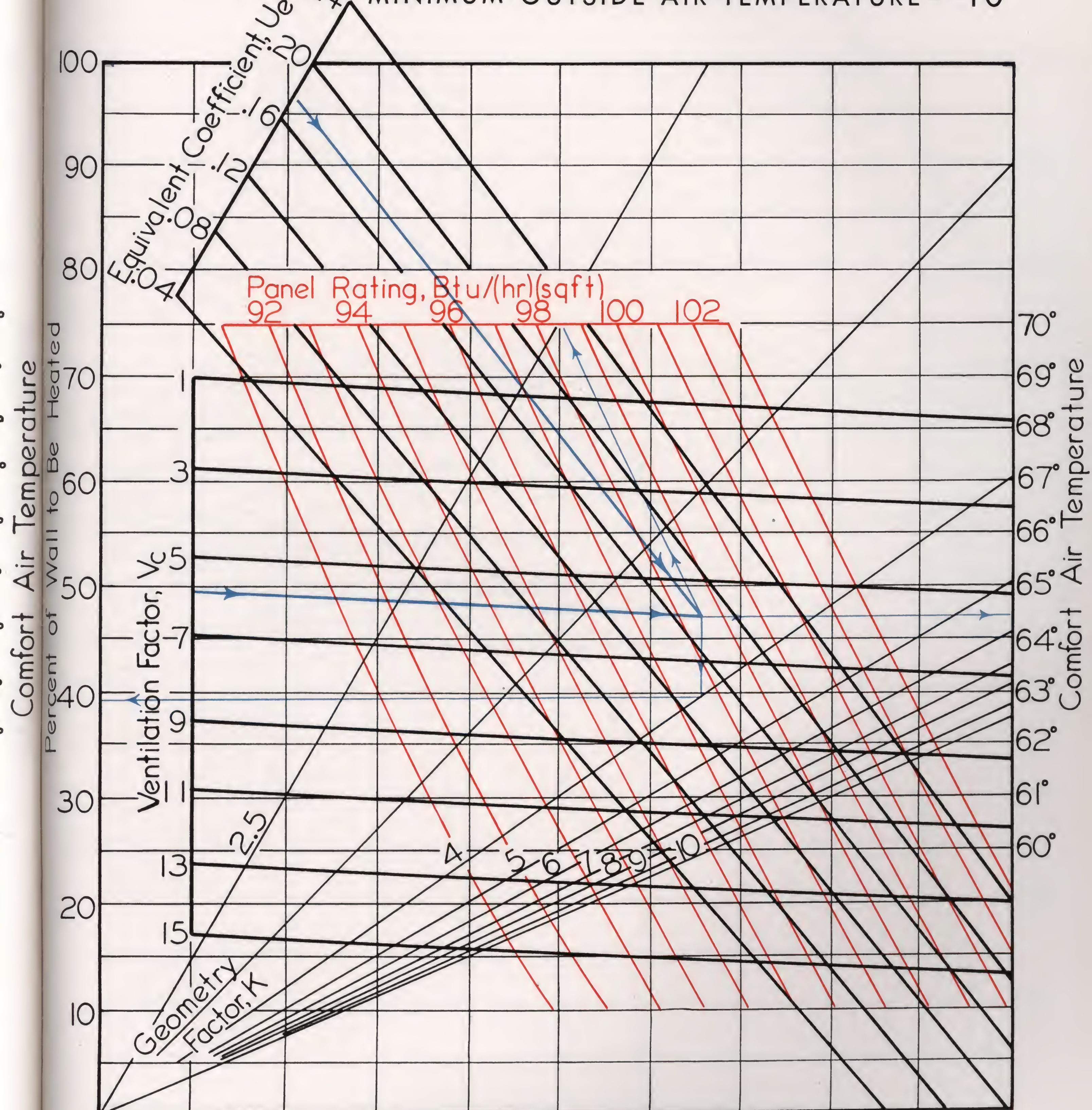


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

WALL PANEL

MAXIMUM PANEL TEMPERATURE = 120°

MINIMUM OUTSIDE AIR TEMPERATURE = −10°

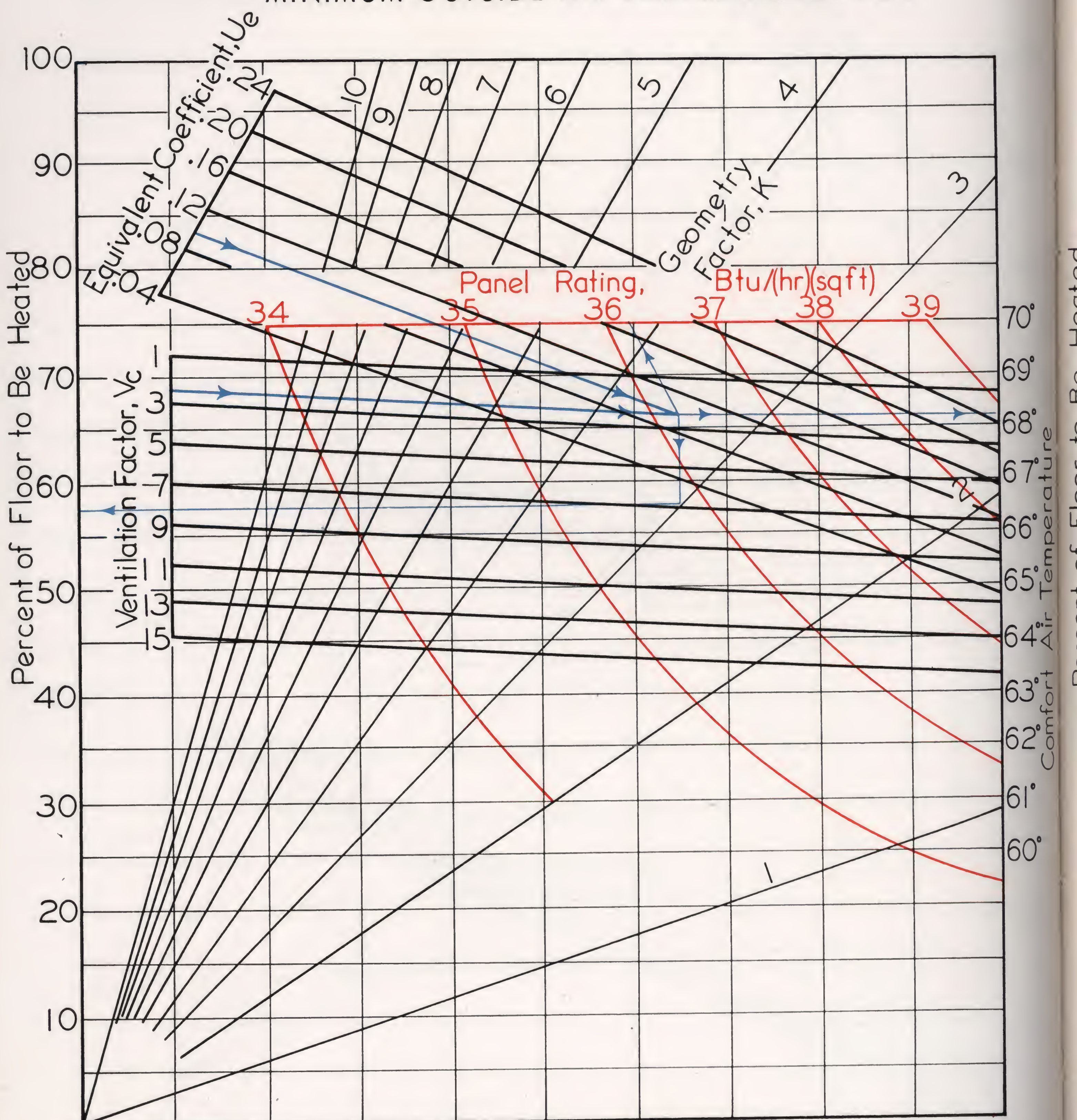


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

MAXIMUM PANEL TEMPERATURE = 85°

MINIMUM OUTSIDE AIR TEMPERATURE = +30°

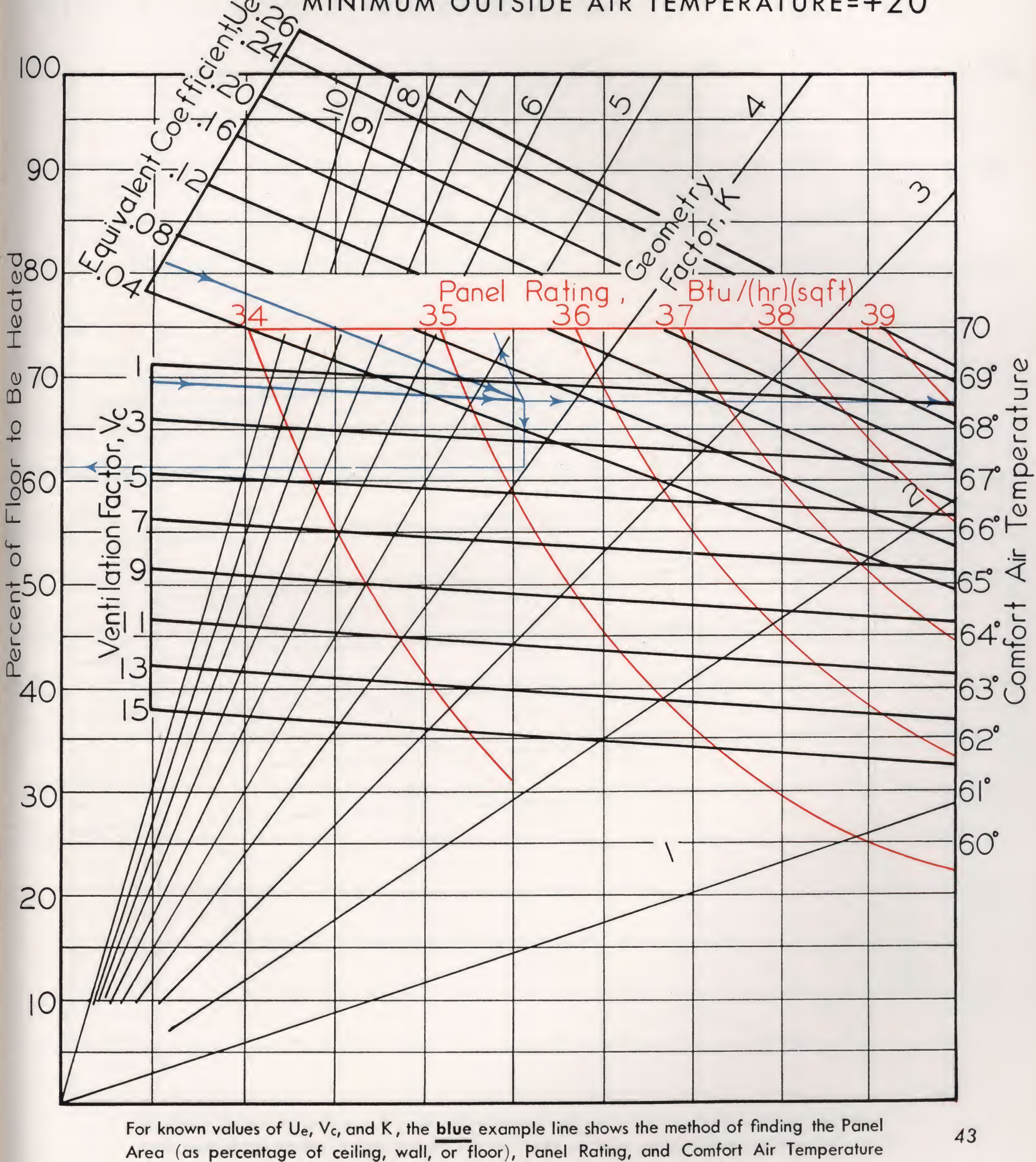


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

MAXIMUM PANEL TEMPERATURE = 85°

MINIMUM OUTSIDE AIR TEMPERATURE = +20°

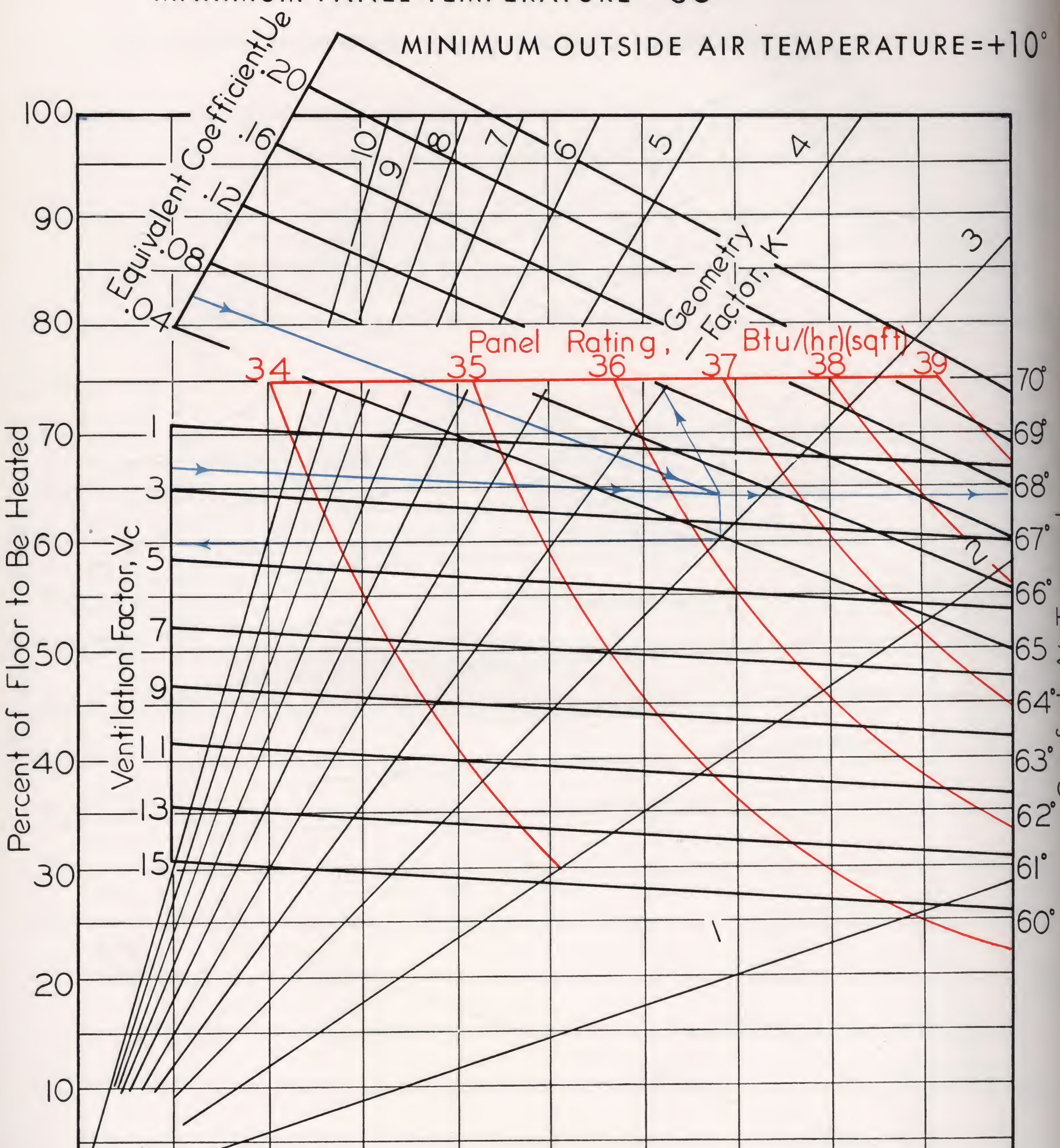


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

MAXIMUM PANEL TEMPERATURE = 85°

MINIMUM OUTSIDE AIR TEMPERATURE = +10°

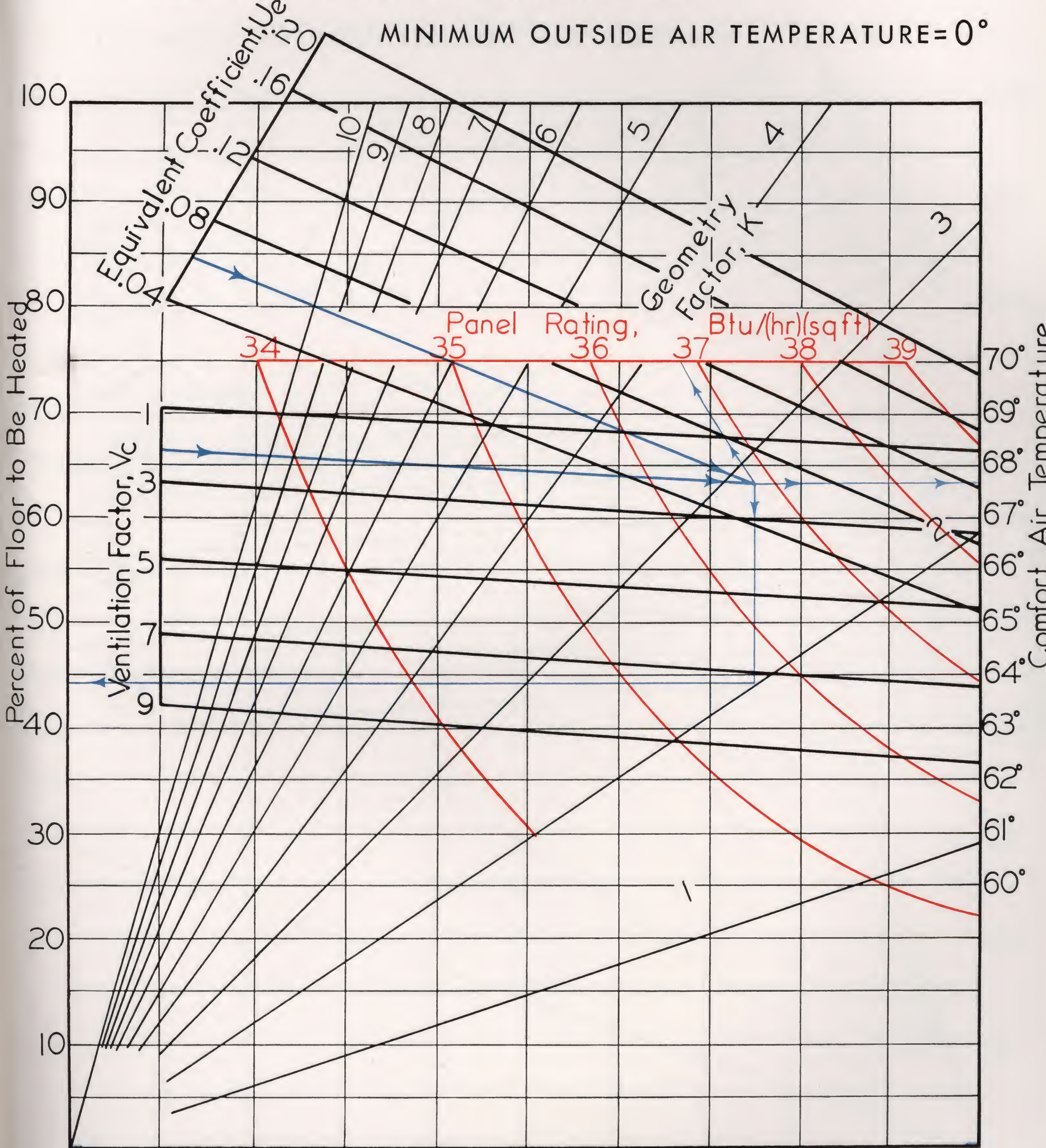


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

MAXIMUM PANEL TEMPERATURE = 85°

MINIMUM OUTSIDE AIR TEMPERATURE = 0°

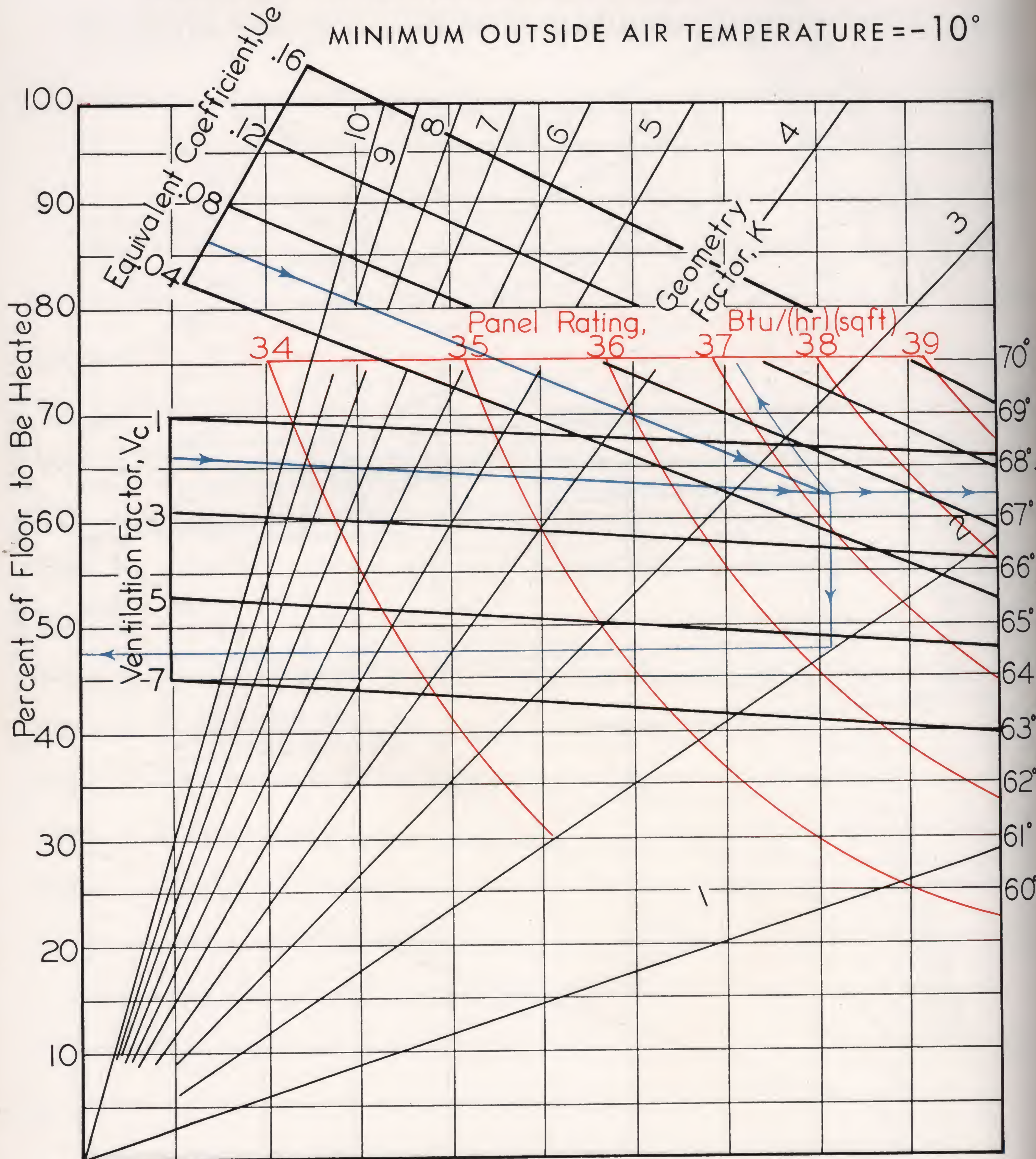


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

MAXIMUM PANEL TEMPERATURE = 85°

MINIMUM OUTSIDE AIR TEMPERATURE = −10°

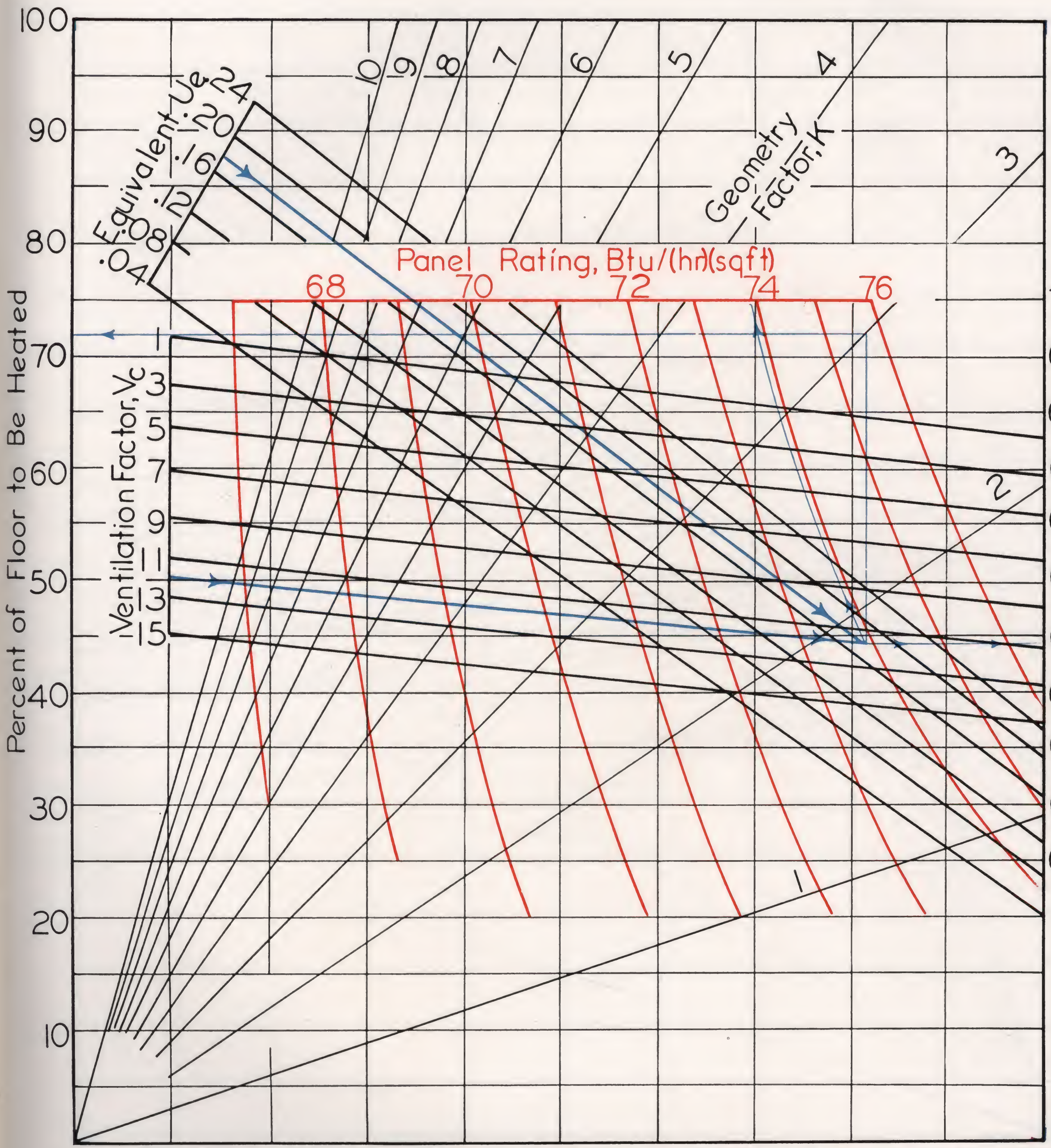


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = +30°

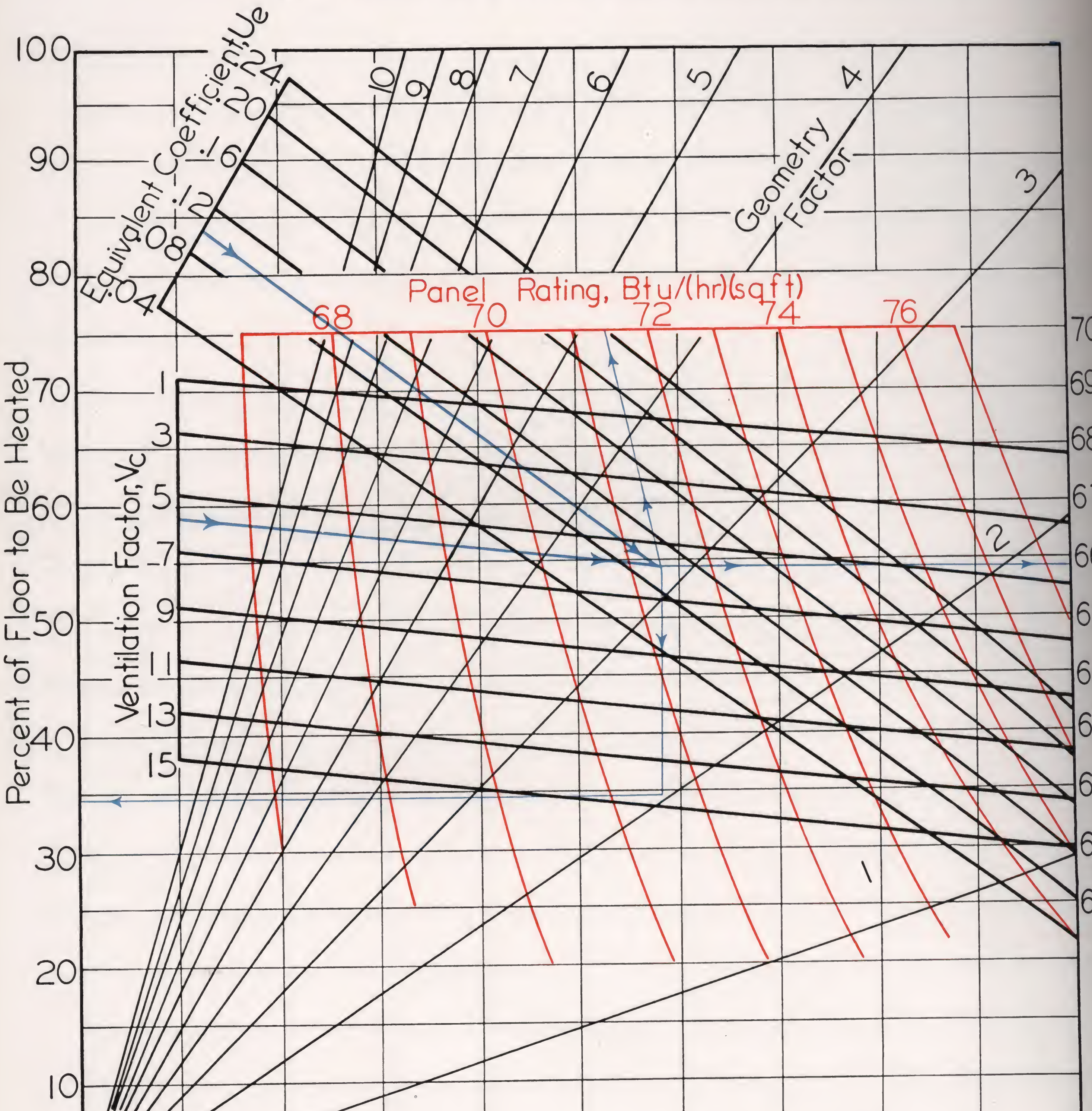


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = +20°

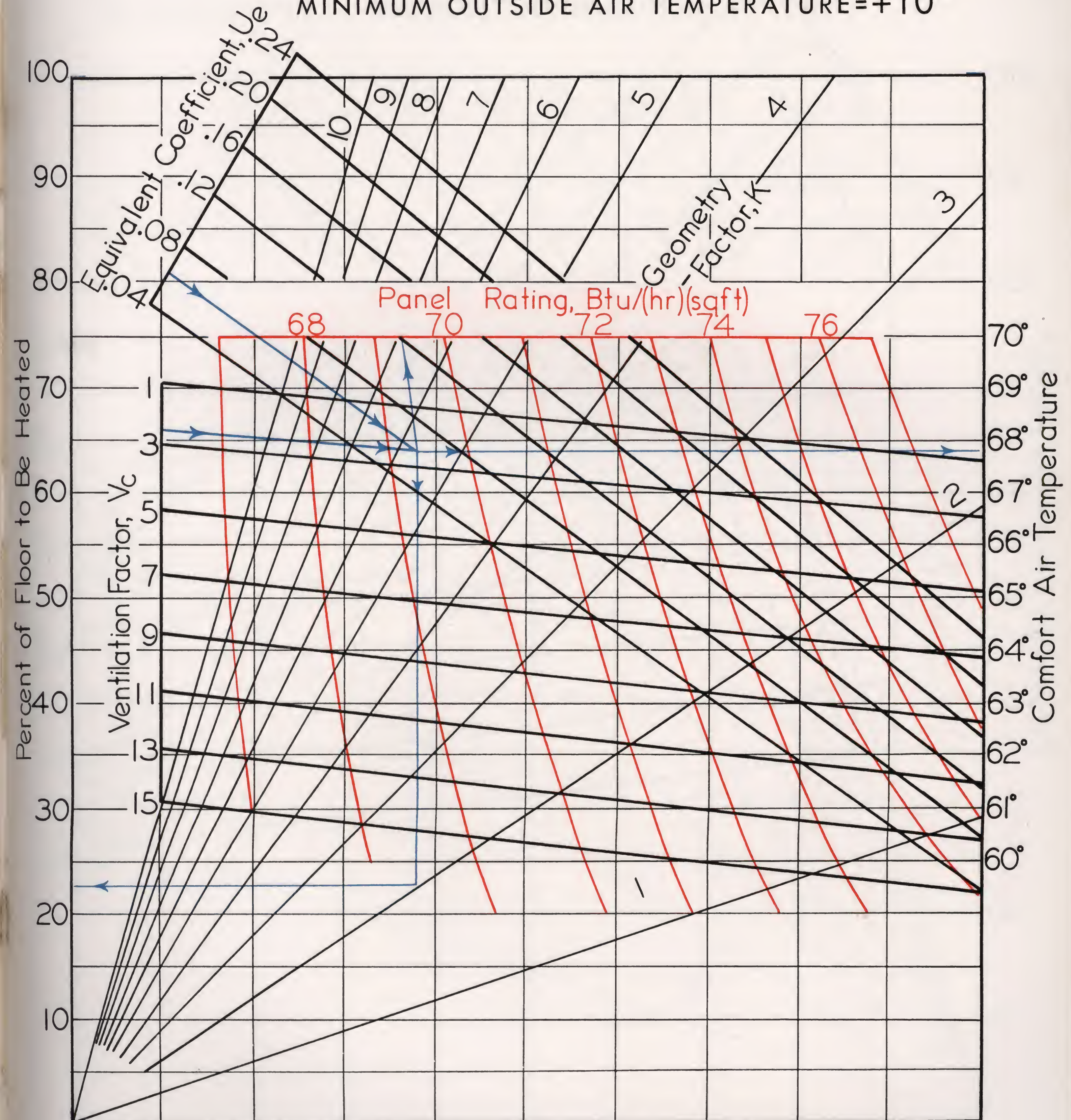


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = +10°

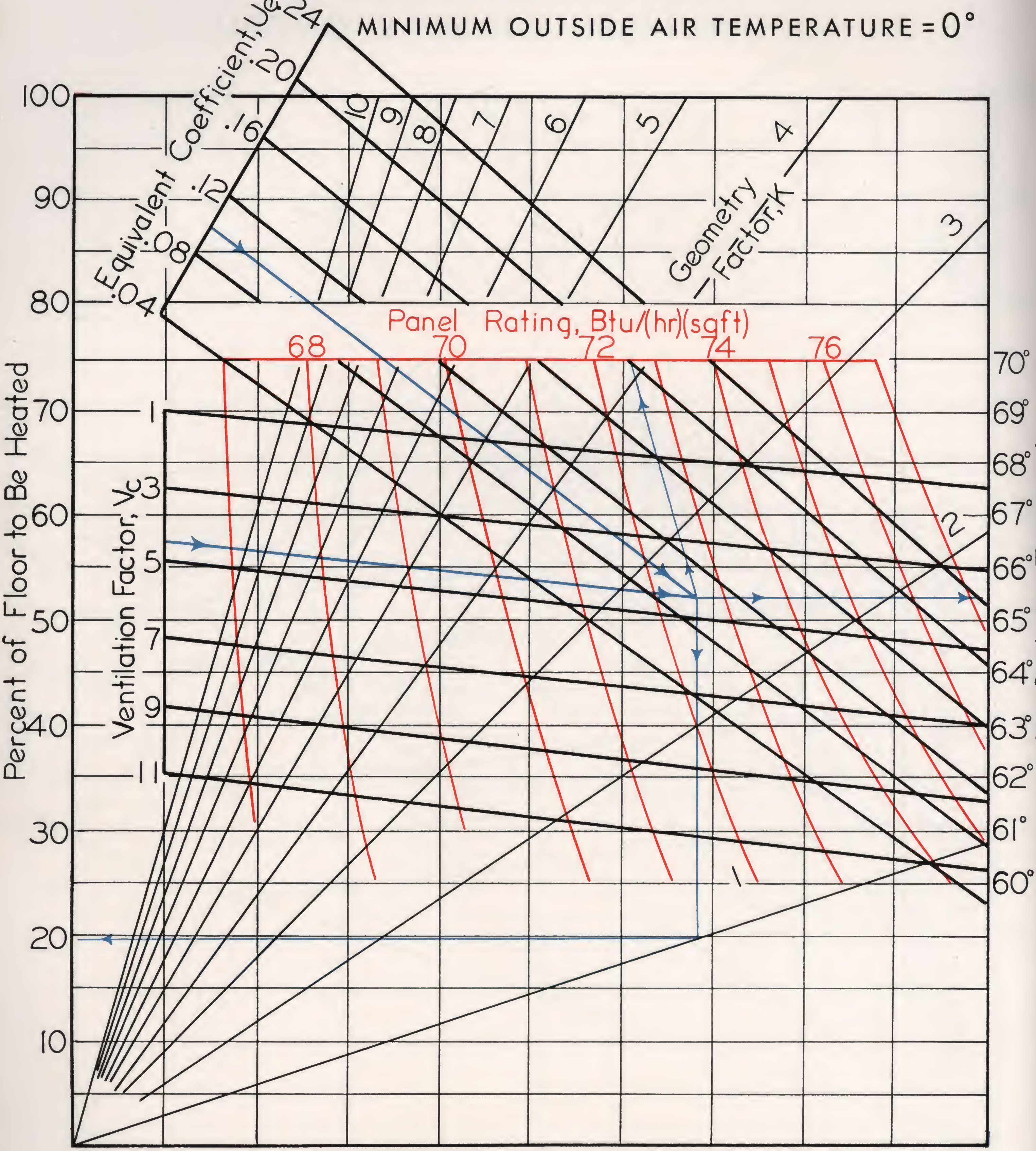


For known values of Ue, Vc, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = 0°

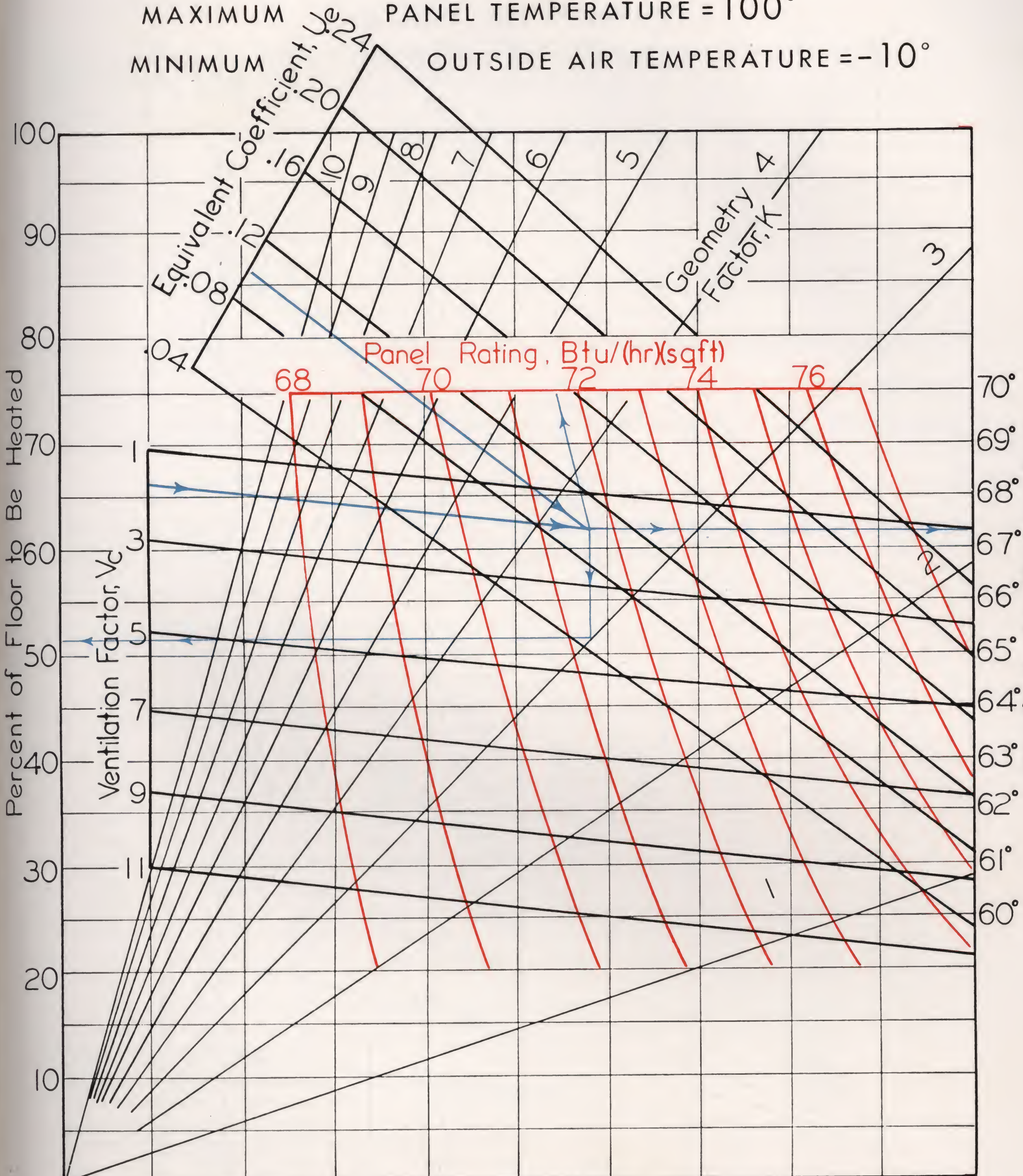


For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOOR PANEL

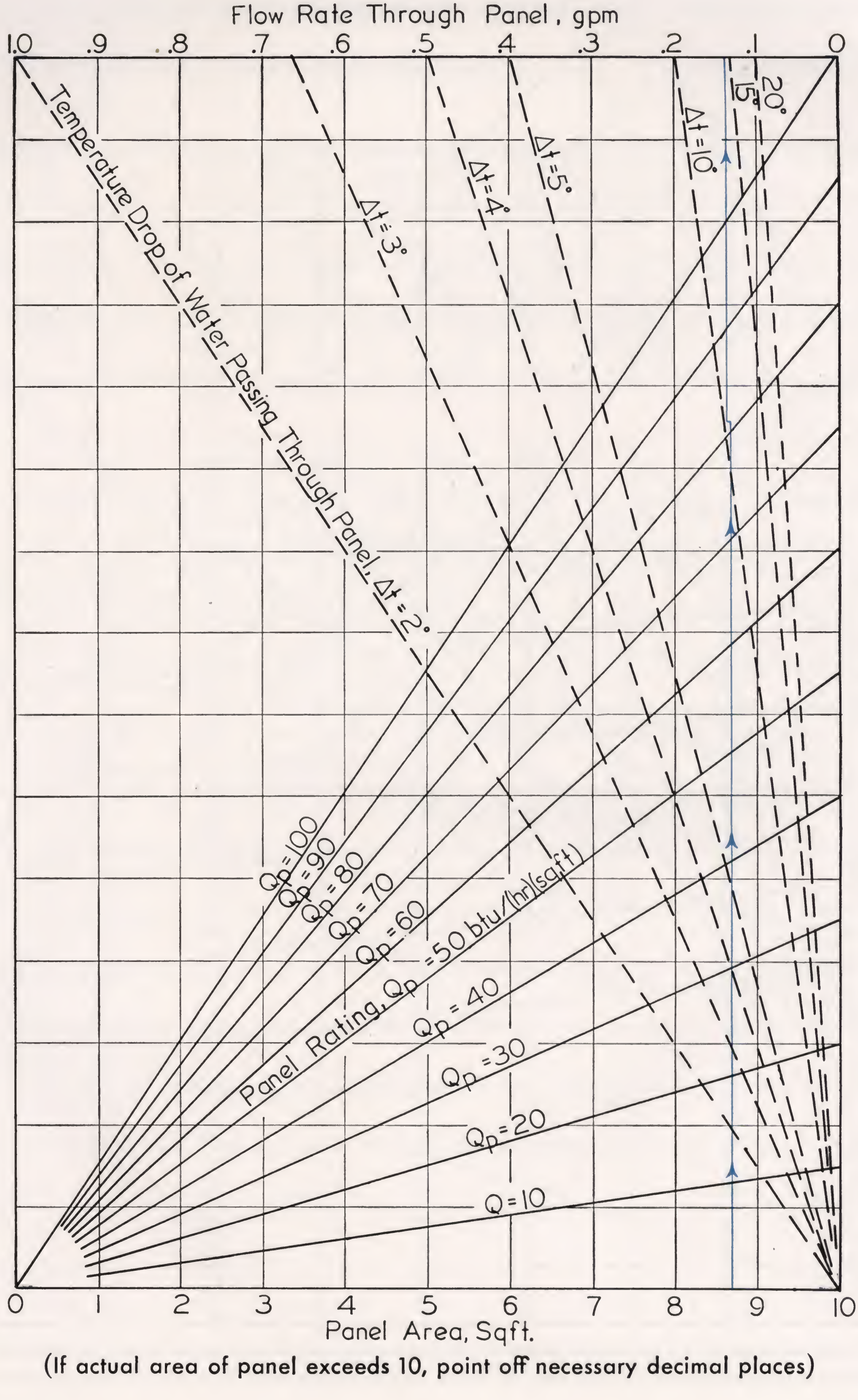
MAXIMUM PANEL TEMPERATURE = 100°

MINIMUM OUTSIDE AIR TEMPERATURE = −10°



For known values of U_e, V_c, and K, the **blue** example line shows the method of finding the Panel Area (as percentage of ceiling, wall, or floor), Panel Rating, and Comfort Air Temperature

FLOW RATE CHART



(If actual area of panel exceeds 10, point off necessary decimal places)

Table I

MEAN WATER TEMPERATURE OF PLASTER PANEL OPERATING WITH 85°F SURFACE TEMPERATURE

PANEL RATING Q_p Btu/(hr)(sq ft)	3/8″ TYPE K COPPER WATER TUBE*			1/2″ TYPE K COPPER WATER TUBE*			3/4″ TYPE K COPPER WATER TUBE*		
	4″ centers	6″ centers	9″ centers	4″ centers	6″ centers	9″ centers	4″ centers	6″ centers	9″ centers
34	99.7	107.7	116.6	99.1	106.9	115.6	98.7	106.3	114.6
35	100.1	108.4	117.5	99.6	107.6	116.5	99.1	106.9	115.5
36	100.5	109.0	118.5	100.0	108.2	117.4	99.5	107.5	116.3
37	100.9	109.7	119.4	100.4	108.9	118.3	99.9	108.1	117.2
38	101.4	110.3	120.4	100.8	109.5	119.2	100.3	108.8	118.1
39	101.8	111.0	121.3	101.3	110.2	120.1	100.7	109.4	118.9
40	102.2	111.7	122.2	101.7	110.8	121.0	101.1	110.0	119.8
41	102.7	112.4	123.1	102.1	111.5	121.9	101.5	110.6	120.5
42	103.1	113.0	124.1	102.5	112.1	122.8	101.9	111.3	121.6

* All tube sizes are for nominal diameter.

NOTE: This table is for copper tube in plaster; the coils are above and in contact with expanded metal lath and the distance from panel face to edge of tube is 1/4″. Water temperatures are for a panel having negligible heat dissipation from the rear surface.

For concrete panels (with copper tubes embedded 1/4″ from tube wall to panel face) the temperature difference between the water and the panel face will be 25% less than the value indicated in the above table for the same value of panel rating.

Table II

MEAN WATER TEMPERATURE OF PLASTER PANEL OPERATING WITH 100°F SURFACE TEMPERATURE

PANEL RATING Q_p Btu/(hr)(sq ft)	3/8″ TYPE K COPPER WATER TUBE*			1/2″ TYPE K COPPER WATER TUBE*			3/4″ TYPE K COPPER WATER TUBE*		
	4″ centers	6″ centers	9″ centers	4″ centers	6″ centers	9″ centers	4″ centers	6″ centers	9″ centers
44	118.9	129.3	140.9	118.3	128.4	139.6	117.7	127.5	138.3
46	119.8	130.7	142.8	119.2	129.7	141.4	118.5	128.8	140.0
48	120.7	132.0	144.7	120.0	131.0	143.2	119.4	130.0	141.8
50	121.5	133.3	146.6	120.8	132.2	145.0	120.2	131.3	143.6
52	122.4	134.7	148.4	121.6	133.7	146.8	121.0	132.5	145.3
54	123.3	136.0	150.2	122.5	134.9	148.6	121.8	133.8	147.1
56	124.1	137.3	152.1	123.3	136.1	150.5	122.6	135.0	148.7
58	125.0	138.7	154.0	124.2	137.4	152.2	123.4	136.3	150.5
60	125.8	140.0	155.9	125.0	138.7	154.1	124.2	137.5	152.3
62	126.7	141.4	157.8	125.8	140.0	155.9	125.0	138.8	154.1
64	127.5	142.6	159.6	126.7	141.4	157.7	125.6	140.0	155.7
66	128.4	144.0	161.5	127.5	142.6	159.5	126.6	141.3	157.5
68	129.3	145.4	163.4	128.3	143.9	161.3	127.4	142.5	159.3
70	130.1	146.7	165.2	129.2	145.2	163.1	128.2	143.8	161.1
72	131.0	148.0	167.0	130.0	146.5	164.9	129.0	145.0	162.8
74	131.9	149.4	169.0	130.8	147.8	166.7	129.8	146.3	164.6
76	132.7	150.8	171.0	131.7	149.1	168.5	130.6	147.5	166.3
78	133.6	152.1	173.8	132.5	150.4	170.4	131.4	148.8	168.1
80	134.4	153.5	174.6	133.3	151.7	172.2	132.2	150.1	169.8

* All tube sizes are for nominal diameter.

NOTE: This table is for copper tube in plaster; the coils are above and in contact with expanded metal lath and the distance from pane lface to edge of tube is 1/4″. Water temperatures are for a panel having negligible heat dissipation from the rear surface.

For concrete panels (with copper tubes embedded 1/4″ from tube wall to panel face) the temperature difference between the water and the panel face will be 25% less than the value indicated in the above table for the same value of panel rating.

Table III

MEAN WATER TEMPERATURE OF PLASTER PANEL OPERATING WITH 120°F SURFACE TEMPERATURE

PANEL RATING Q_p Btu/(hr)(sq ft)	3/8″ TYPE K COPPER WATER TUBE*			1/2″ TYPE K COPPER WATER TUBE*			3/4″ TYPE K COPPER WATER TUBE*		
	4″ centers	6″ centers	9″ centers	4″ centers	6″ centers	9″ centers	4″ centers	6″ centers	9″ centers
74	151.9	169.4	189.0	150.8	167.8	186.7	149.8	166.3	184.6
76	152.7	170.8	191.0	151.7	169.1	188.5	150.6	167.5	186.3
78	153.6	172.1	193.8	152.5	170.4	190.4	151.4	168.8	188.1
80	154.5	173.5	194.6	153.3	171.7	192.2	152.2	170.1	189.8
82	155.3	174.8	196.4	154.2	173.0	194.0	153.0	171.3	191.6
84	156.1	176.1	198.4	155.0	174.3	195.8	153.9	172.6	193.3
86	157.0	177.5	200.2	155.8	175.6	197.6	154.6	173.9	195.1
88	157.9	178.8	202.0	156.7	176.9	199.4	155.5	175.1	196.8
90	158.8	180.1	203.8	157.5	178.2	201.3	156.3	176.4	198.5
92	159.6	181.5	205.8	158.3	179.5	203.0	157.1	177.6	200.3
94	160.5	182.9	207.7	159.1	180.7	204.8	157.9	178.9	202.1
96	161.3	184.2	209.5	160.0	182.1	206.7	158.7	180.1	203.9
98	162.3	185.5	211.4	160.8	183.4	208.5	159.5	181.4	205.7
100	163.1	186.7	213.3	161.7	184.7	210.2	160.3	182.7	207.3
102	164.0	188.2	215.2	162.5	186.0	212.0	161.1	183.8	209.1
104	164.8	189.5	217.1	163.4	187.3	213.9	162.0	185.2	210.8

* All tube sizes are for nominal diameter.

NOTE: This table is for copper tube in plaster; the coils are above and in contact with expanded metal lath and the distance from panel face to edge of tube is 1/4″. Water temperatures are for a panel having negligible heat dissipation from the rear surface.

For concrete panels (with copper tubes embedded 1/4″ from tube wall to panel face) the temperature difference between the water and the panel face will be 25% less than the value indicated in the above table for the same value of panel rating.

B I B L I O G R A P H Y

1 Panel Heating and Cooling Analysis, *Raber and Hutchinson*, ASHVE Transactions, Vol. 47, 1941.

2 Load Calculation Procedure for Electric Panel Space Heating, *Raber and Hutchinson*, AIEE Transactions, 1944.

3 Radiant Energy Exchange as a Factor in Airplane Cabin Heating, *Raber and Hutchinson*, Journal of the Aeronautical Sciences, Vol. II, 1944.

4 A Single-equation Design Procedure for Radiant Panel Systems, *Hutchinson*, Heating, Piping and Air Conditioning, October, 1945.

REVERE COPPER AND BRASS INCORPORATED

Executive Offices: 230 Park Avenue, New York 17, N. Y.

DIVISION OFFICES AND MILLS

BALTIMORE DIVISION
P. O. Box 2075
1301 Wicomico Street
Baltimore 3, Md.
Phone: Gilmor 0222
Teletype: BA 164

ROME DIVISION
Rome, New York
Phone: Rome 2000
Teletype: ROME N Y 447

DALLAS DIVISION
2200 No. Natchez Avenue
Chicago 35, Ill.
Phone: Merrimac 2600
Teletype: CG 957

MICHIGAN DIVISION
5851 West Jefferson Avenue
Detroit 9, Mich.
Phone: Vinewood 1–7350
Teletype: DE 237

MAGNESIUM-ALUMINUM DIVISION
P. O. Box 2075
1301 Wicomico Street
Baltimore 3, Md.
Phone: Gilmor 0222
Teletype: BA 164

NEW BEDFORD DIVISION
24 North Front Street
New Bedford, Mass.
Phone: New Bedford 8–5601
Teletype: NB 87

CHICAGO MANUFACTURING DIVISION
2200 No. Natchez Avenue
Chicago 35, Ill.
Phone: Merrimac 2600
Teletype: CG 957

ROME MANUFACTURING COMPANY DIVISION
Rome, New York
Phone: Rome 2800
Teletype: ROME N Y 449

DISTRICT SALES OFFICES

Atlanta 3, Ga.
Rhodes-Haverty Bldg.
Phone: Main 2142
Teletype: AT 96

Boston 10, Mass.
140 Federal Street
Phone: Hubbard 7190

Buffalo 7, N. Y.
1807 Elmwood Avenue
Phone: Delaware 7616

Cincinnati 2, Ohio
Carew Tower
Phone: Main 0130
Teletype: CI 171

Cleveland 15, Ohio
Midland Bldg.
Phone: Cherry 3930
Teletype: CV 572

Dallas 1, Texas
Tower Petroleum Bldg.
Phone: Central 8681
Teletype: DL 88

Dayton 2, Ohio
Mutual Home Bldg.
Phone: Hemlock 3271 & 8921
Teletype: DY 107

Grand Rapids 2, Mich.
Keeler Building
Phone: Grand Rapids 9-3301
Teletype: GR 376

Hartford 3, Conn.
410 Asylum Street
Phone: Hartford 7–8174
Teletype: HF 87

Houston 2, Texas
Mellie Esperson Bldg.
Phone: Fairfax 7932

Indianapolis 4, Ind.
Circle Tower
Phone: Market 1908

Los Angeles 15, Calif.
714 W. Olympic Blvd.
Phone: Richmond 9314

Milwaukee 2, Wis.
626 E. Wisconsin Avenue
Phone: Marquette 1440
Teletype: MI 292

Minneapolis 2, Minn.
Metropolitan Bldg.
Phone: Atlantic 3285

New York 17, N. Y.
New York Central Bldg.
75 East 45th Street
Phone: Murray Hill 9–6800
Teletype: NY 1–1222

Philadelphia 3, Pa.
Sixteen Sixteen
Walnut St. Bldg.
Phone: Pennypacker 6133
Teletype: PH 206

Pittsburgh 19, Pa.
Gulf Bldg.
Phone: Court 4342
Teletype: PG 572

Providence 3, R. I.
Industrial Trust Bldg.
Phone: Gaspee 8110

St. Louis 1, Mo.
Telephone Bldg.
1010 Pine Street
Phone: Garfield 4416
Teletype: SL 191

San Francisco 4, Calif.
Russ Bldg.
Phone: Sutter 0282

Seattle 1, Wash.
1331 Third Avenue
Phone: Main 8372

November 5, 1945

Printed in U. S. A